

**(12) United States Patent**
Schwartz et al.**(10) Patent No.: US 9,378,192 B2**
(45) Date of Patent: Jun. 28, 2016**(54) MEMORY CONTROLLER AND METHOD OF OPERATING THE SAME****(71) Applicant: SAMSUNG ELECTRONICS CO., LTD.,** Suwon-si, Gyeonggi-do (KR)**(72) Inventors: Moshe Schwartz,** Rehovot (IL); **Hong Rak Son,** Anyang-si (KR); **Jun Jin Kong,** Yongin-si (KR); **Jung Soo Chung,** Seoul (KR)**(73) Assignee: Samsung Electronics Co., Ltd.,** Suwon-si, Gyeonggi-do (KR)**(*) Notice:** Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 101 days.**(21) Appl. No.: 14/205,478****(22) Filed: Mar. 12, 2014****(65) Prior Publication Data**

US 2014/0281816 A1 Sep. 18, 2014

(30) Foreign Application Priority Data

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(51) Int. Cl.**G06F 11/00** (2006.01)
G06F 17/22 (2006.01)
H03M 13/15 (2006.01)
H03M 13/29 (2006.01)
G06F 11/10 (2006.01)**(52) U.S. Cl.**CPC **G06F 17/2223** (2013.01); **G06F 11/004** (2013.01); **G06F 17/2217** (2013.01); **G06F 11/1072** (2013.01); **H03M 13/152** (2013.01); **H03M 13/2906** (2013.01)**(58) Field of Classification Search**CPC **G06F 11/1072**; **G06F 17/2223**; **G06F 17/2217**; **H03M 13/152**; **H03M 13/2906**

USPC 714/768

See application file for complete search history.

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Primary Examiner — James C Kerveros*(74) Attorney, Agent, or Firm* — Volentine & Whitt, PLLC**(57) ABSTRACT**

A method of operating a memory controller is provided. The method includes determining a data state based on an input stream including multiple alphabet letters, converting a part of the input stream, which corresponds to a conversion size, into alphabet letters in a lower numeral system when the data state is determined to be a first state among multiple predetermined data states, inserting one of the converted alphabet letters into the input stream, and outputting each of the alphabet letters in the input stream as is when the data state is determined to be a second state among the predetermined data states.

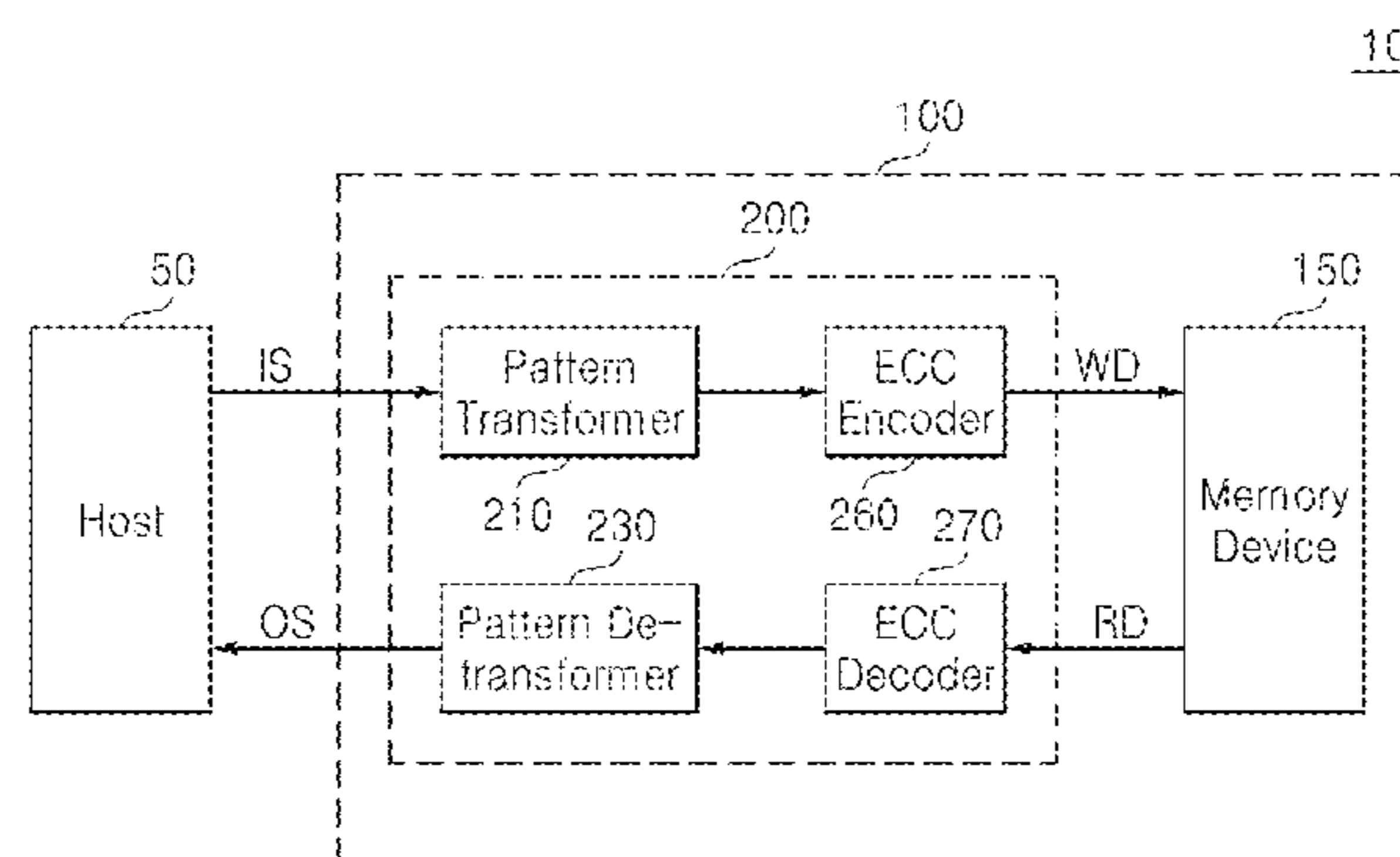
19 Claims, 20 Drawing Sheets

FIG. 1

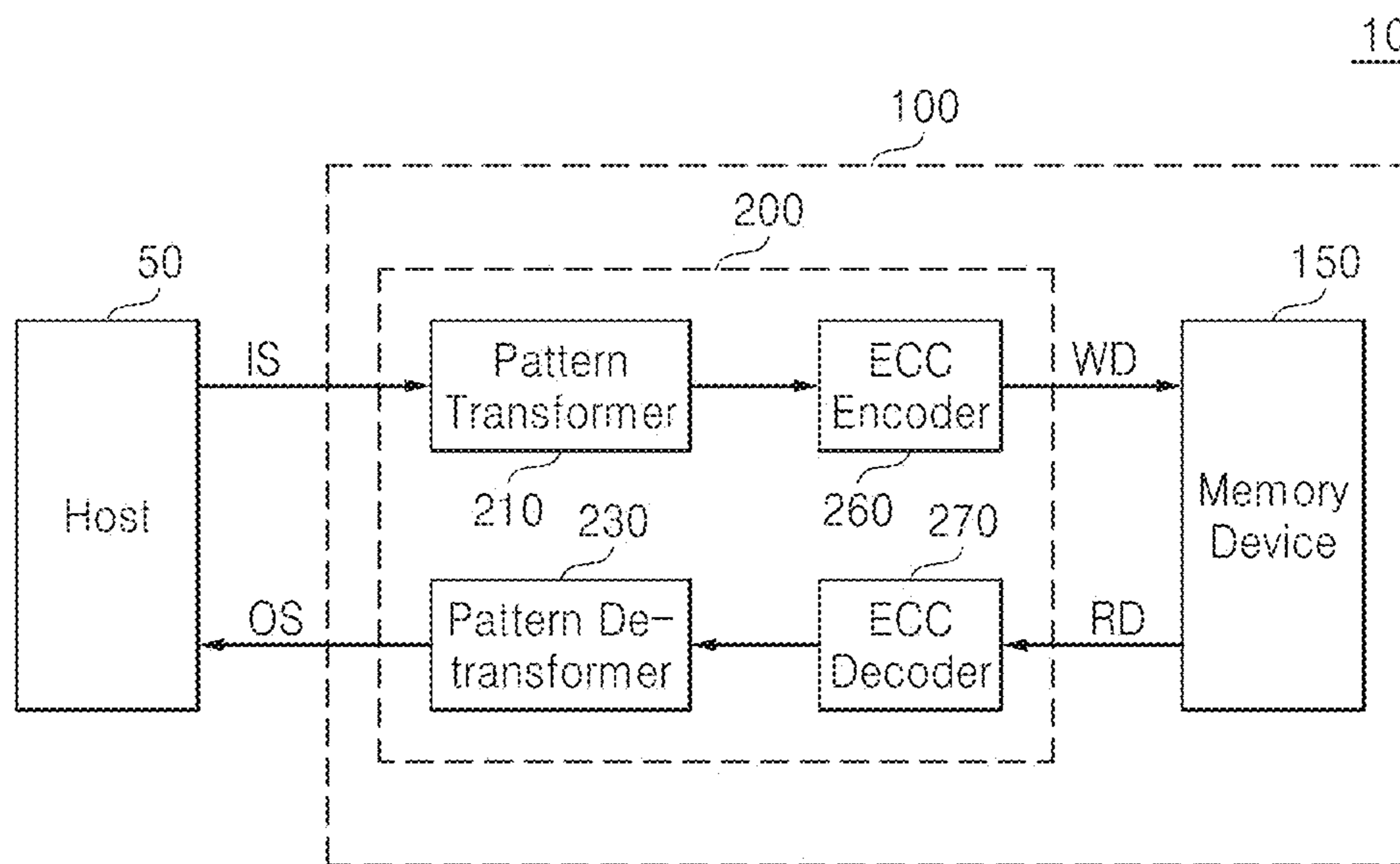


FIG. 2

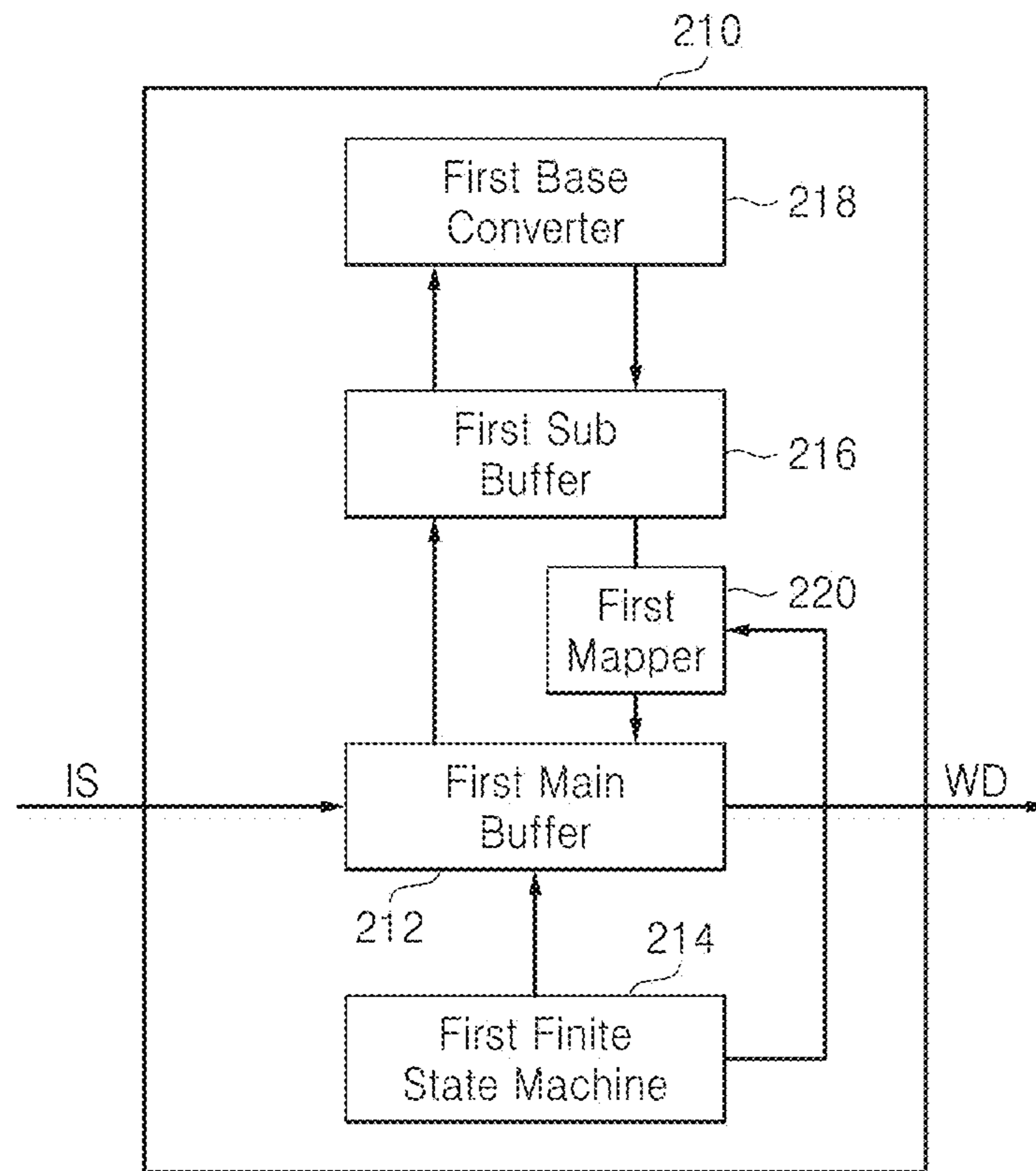


FIG. 3

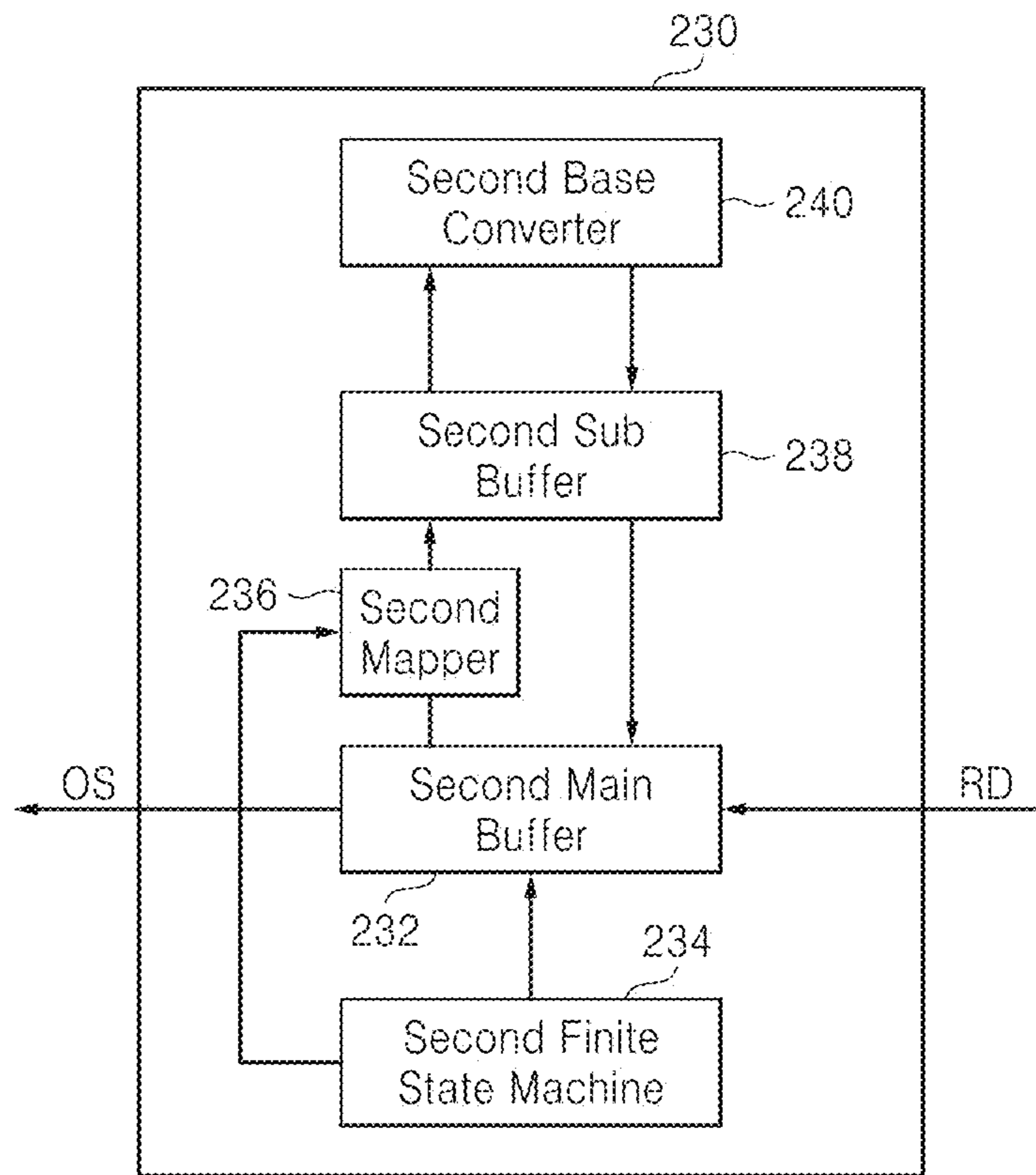


FIG. 4

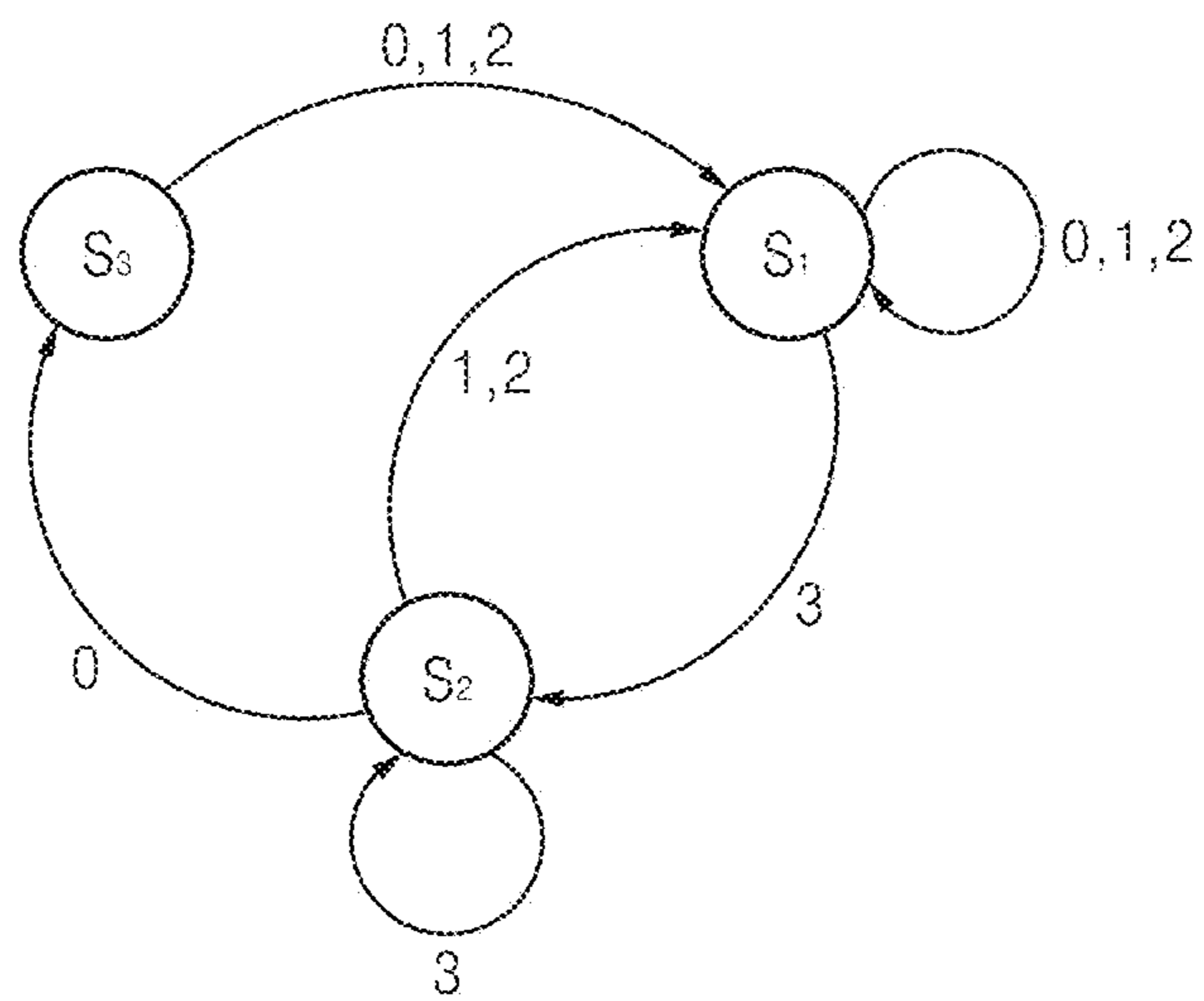


FIG. 5

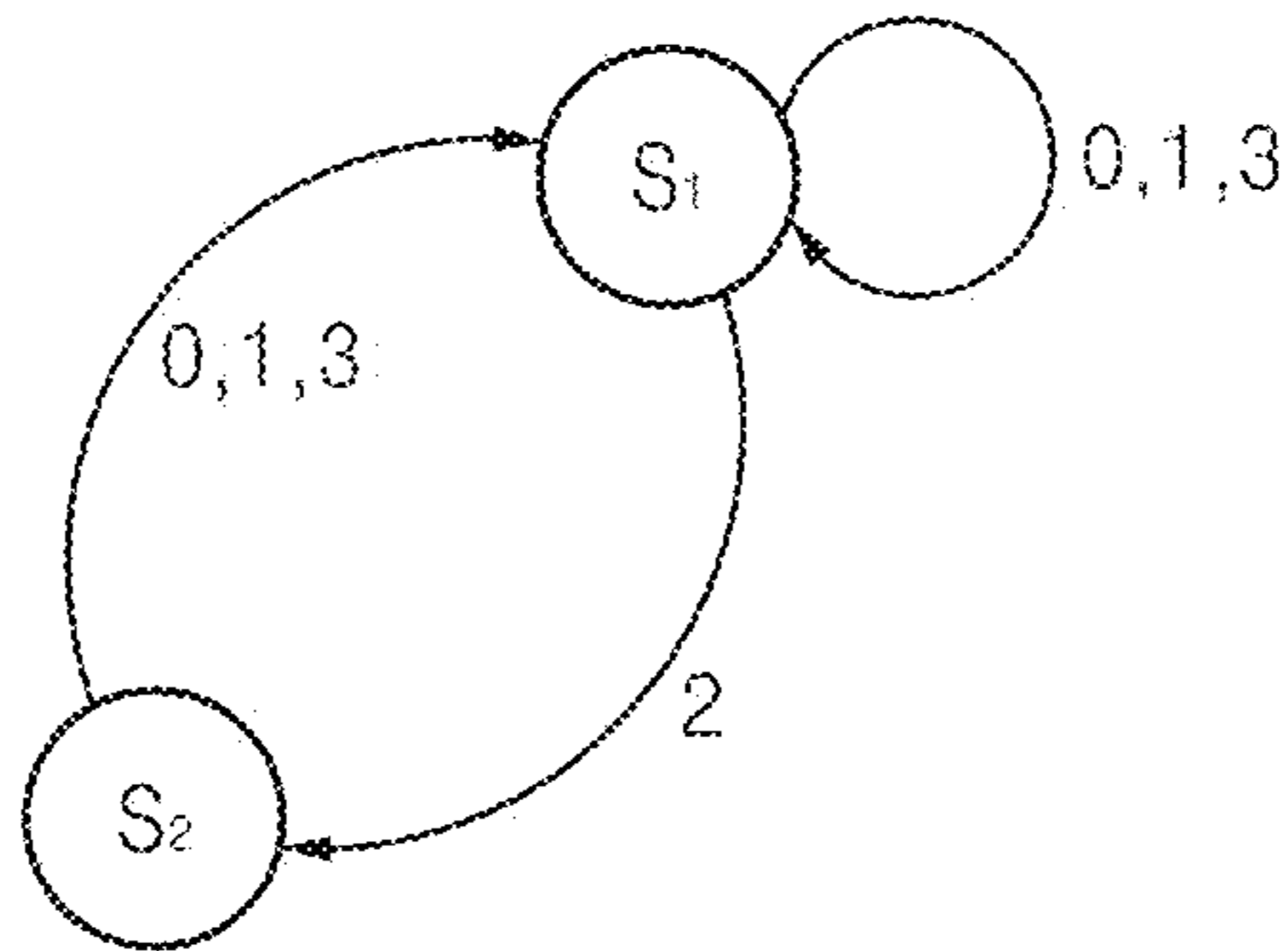


FIG. 6

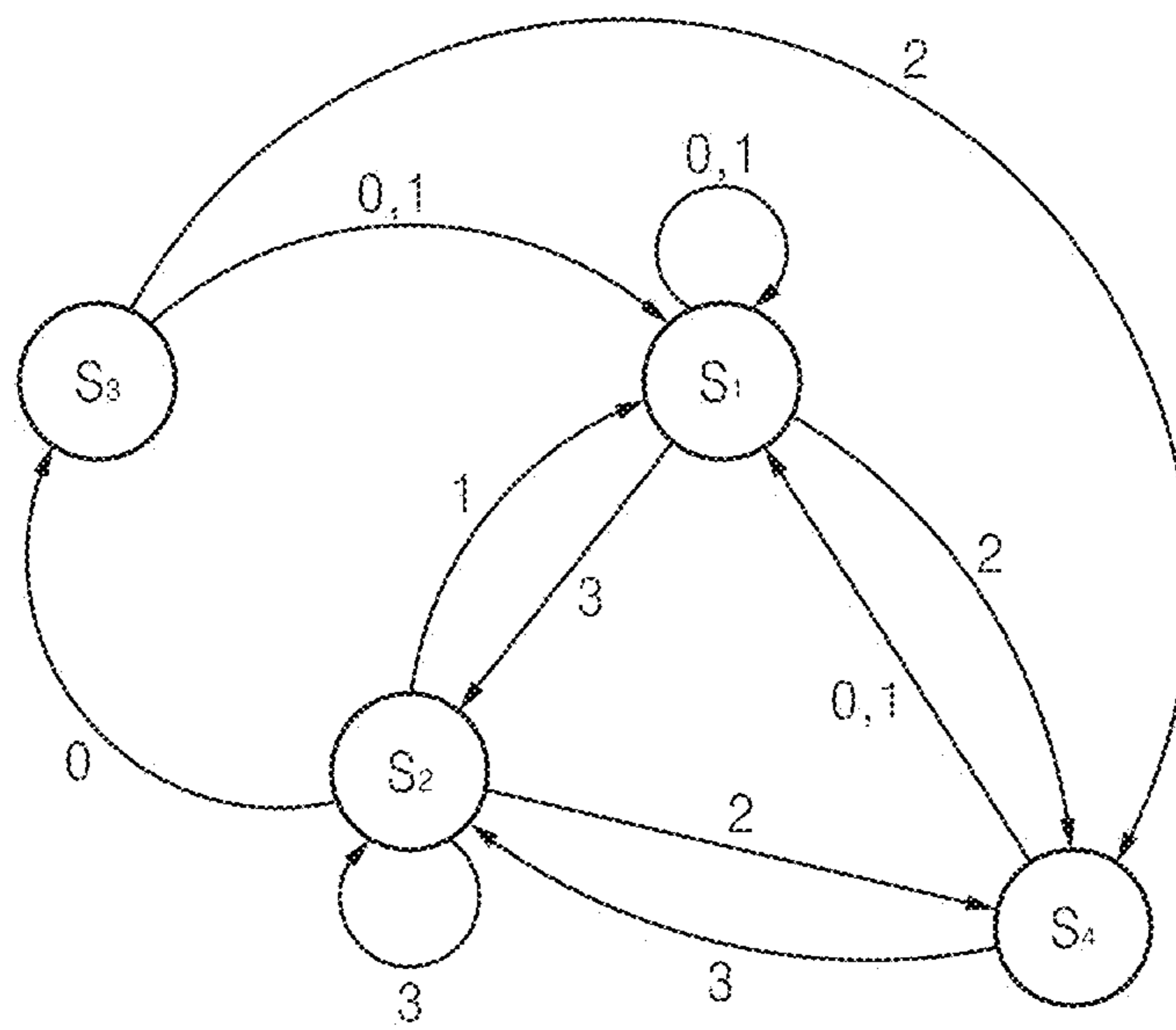


FIG. 7

S3		
BASE- CONVERTED ALPHABET		MAPPED ALPHABET
0	→	0
1	→	1
2	→	2

FIG. 8

S2		
BASE- CONVERTED ALPHABET		MAPPED ALPHABET
0	→	0
1	→	1
2	→	3

FIG. 9

S3			S4		
BASE- CONVERTED ALPHABET		MAPPED ALPHABET	BASE- CONVERTED ALPHABET		MAPPED ALPHABET
0	→	0	0	→	0
1	→	1	1	→	1
2	→	2	2	→	3

FIG. 10A

Input Time	Current State	Pattern Avoidance	Input	Pre-Output Buffer (First Sub-Buffer)	Output Time	Change of State	Post-Output Buffer (First Sub-Buffer)
1	Initial		1		1	Initial → S1	
2	S1		2		2	S1 → S4	
3	S4	Base- Converting	3				
4			0				
5			3				
6			0				
7			0				
8			0				
9			0				
10			0				
11			0				
12			0				
13			0				
14			0				
15			0				
16			0				
17			0				
18			0				
19			0				
20			0				
21			0	2,0,2,2,1,1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	3	S4 → S2	0,2,2,2,1,1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
22	S2		0	0,2,2,2,1,1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	4	S2 → S3	0,2,2,2,1,1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
	S3	Pattern Avoidance		0,2,2,2,1,1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	5	S3 → S1	2,2,2,1,1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0

FIG. 10B

Input Time	Current State	Pattern Avoidance	Input	Pre-Output Buffer (First Sub Buffer)	Output Time	Change of State	Post-Output Buffer (First Sub Buffer)
23	S1		0	2,2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	6	S1→S1	2,2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
24	S1		3	2,2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	7	S1→S2	2,2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
25	S2		1	2,2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	8	S2→S1	2,2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
26	S1		2	2,2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	9	S1→S4	2,2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
	S4	Pattern Avoidance		2,2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	10	S4→S2	2,2,1,1,0,1,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
27	S2		3	2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	11	S2→S2	2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
28	S2		0	2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	12	S2→S3	2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
	S3	Pattern Avoidance		2,2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	13	S3→S4	2,1,1,0,1,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
	S4	Pattern Avoidance		2,1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	14	S4→S2	1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
29	S2		3	1,1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	15	S2→S2	1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
30	S2		3	1,1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	16	S2→S2	1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
31	S2		0	1,1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	17	S2→S3	1,1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
	S3	Pattern Avoidance		1,1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	18	S3→S1	1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
32	S1		0	1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	19	S1→S1	1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
33	S1		3	1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	20	S1→S2	1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
34	S2		0	1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	21	S2→S3	1,0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
	S3	Pattern Avoidance		1,0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	22	S3→S1	0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
35	S1		1	0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	23	S1→S1	0,1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0

FIG. 10C

Inout	Current State	Pattern Avoidance	Inout	Pre-Output Buffer (First Sub Buffer)	Now (Time)	Change of State	Post-Output Buffer (First Sub Buffer)
36	S1		3	0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	24	S1→S2	0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
37	S2		0	0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	25	S2→S3	0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
	S3	Pattern Avoidance		0,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	26	S3→S1	1,1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
38	S1		2	1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	27	S1→S4	1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
	S4	Pattern Avoidance		1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	28	S4→S1	1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
39	S1		2	1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	29	S1→S4	1,1,1,2,0,0,0,1,2,0,0,2,1,2,0
	S4	Pattern Avoidance		1,1,1,2,0,0,0,1,2,0,0,2,1,2,0	30	S4→S1	1,1,2,0,0,0,1,2,0,0,2,1,2,0
40	S1		2	1,1,2,0,0,0,1,2,0,0,2,1,2,0	31	S1→S4	1,1,2,0,0,0,1,2,0,0,2,1,2,0
	S4	Last Padding		1,1,2,0,0,0,1,2,0,0,2,1,2,0	32		1,2,0,0,0,1,2,0,0,2,1,2,0
	S4			1,2,0,0,0,1,2,0,0,2,1,2,0	33		2,0,0,0,1,2,0,0,2,1,2,0
	S4			2,0,0,0,1,2,0,0,2,1,2,0	34		0,0,0,1,2,0,0,2,1,2,0
	S4			0,0,0,1,2,0,0,2,1,2,0	35		0,0,1,2,0,0,2,1,2,0
	S4			0,0,1,2,0,0,2,1,2,0	36		0,1,2,0,0,2,1,2,0
	S4			0,1,2,0,0,2,1,2,0	37		1,2,0,0,2,1,2,0
	S4			1,2,0,0,2,1,2,0	38		2,0,0,2,1,2,0
	S4			2,0,0,2,1,2,0	39		0,0,2,1,2,0
	S4			0,0,2,1,2,0	40		0,2,1,2,0
	S4			0,2,1,2,0	41		2,1,2,0
	S4			2,1,2,0	42		1,2,0
	S4			1,2,0	43		2,0
	S4			2,0	44		0
	S4			0	45		

FIG. 11

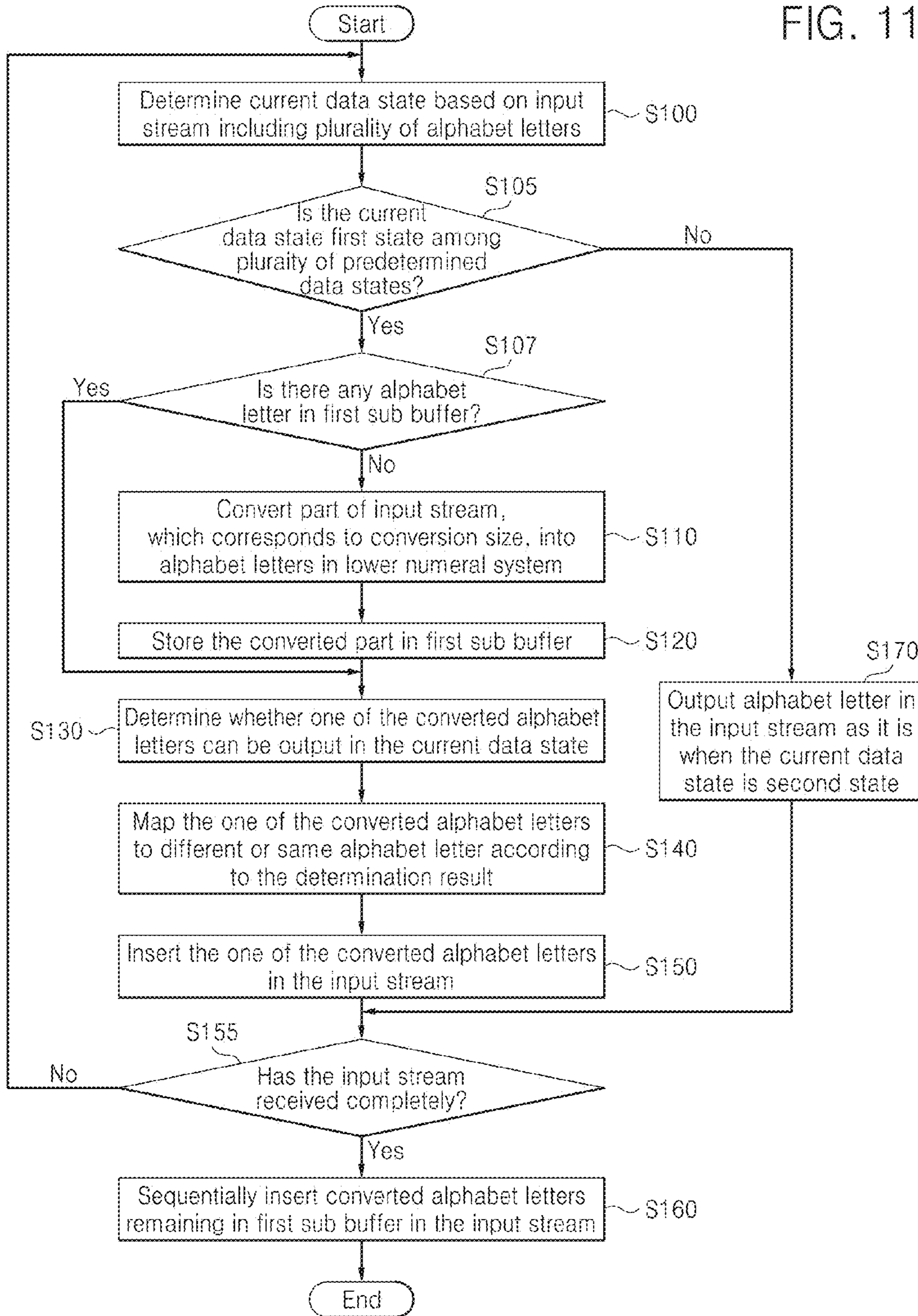


FIG. 12

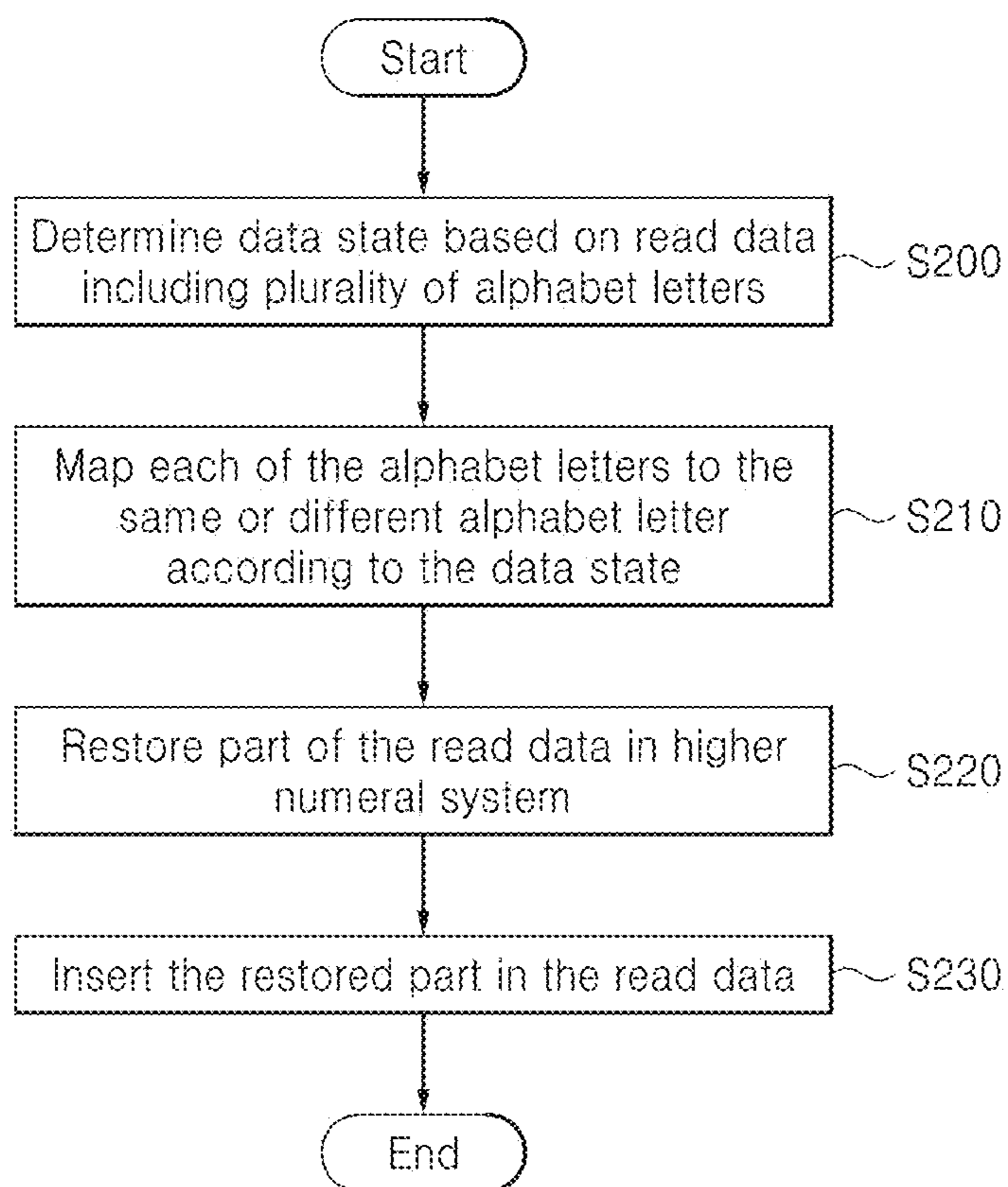


FIG. 13

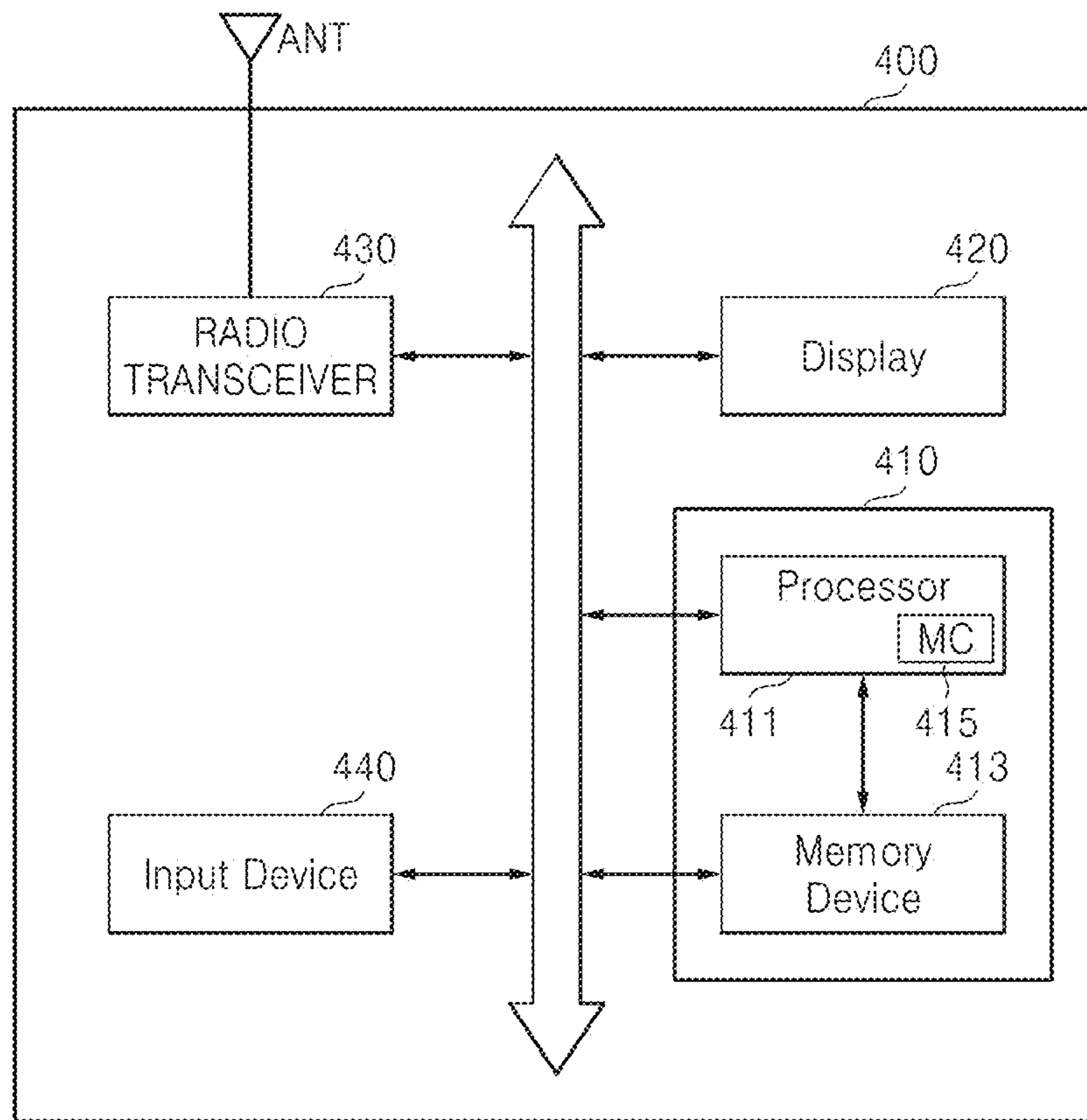


FIG. 14

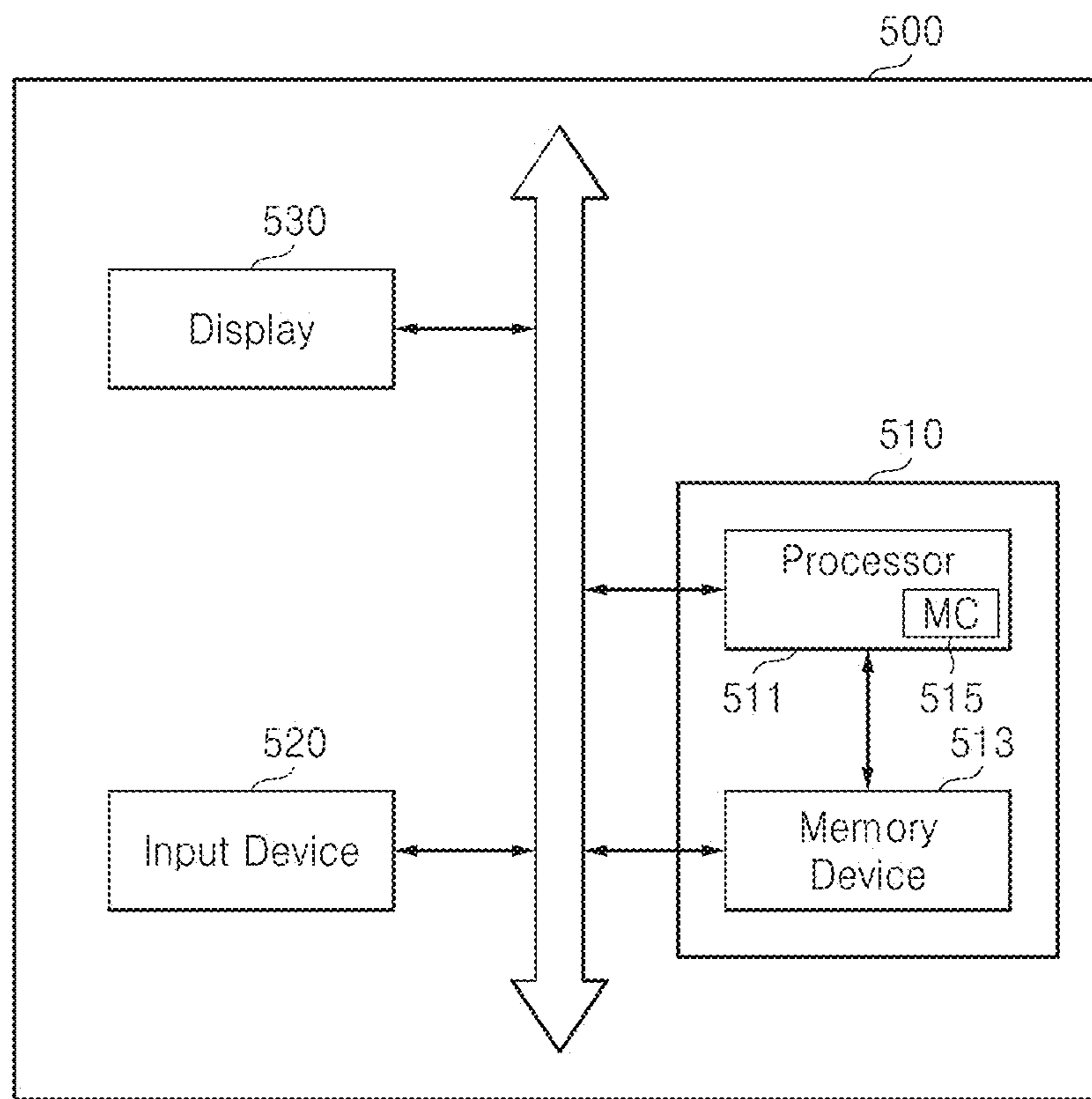


FIG. 15

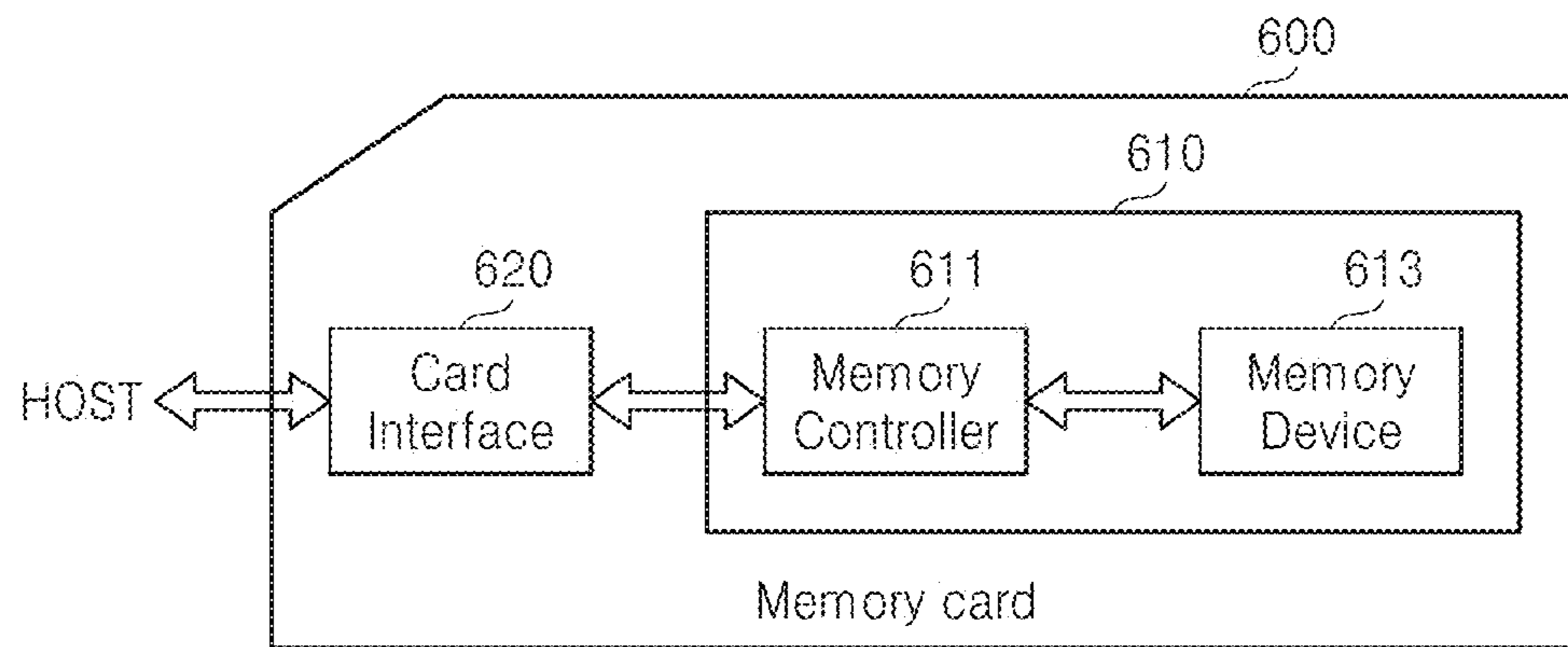


FIG. 16

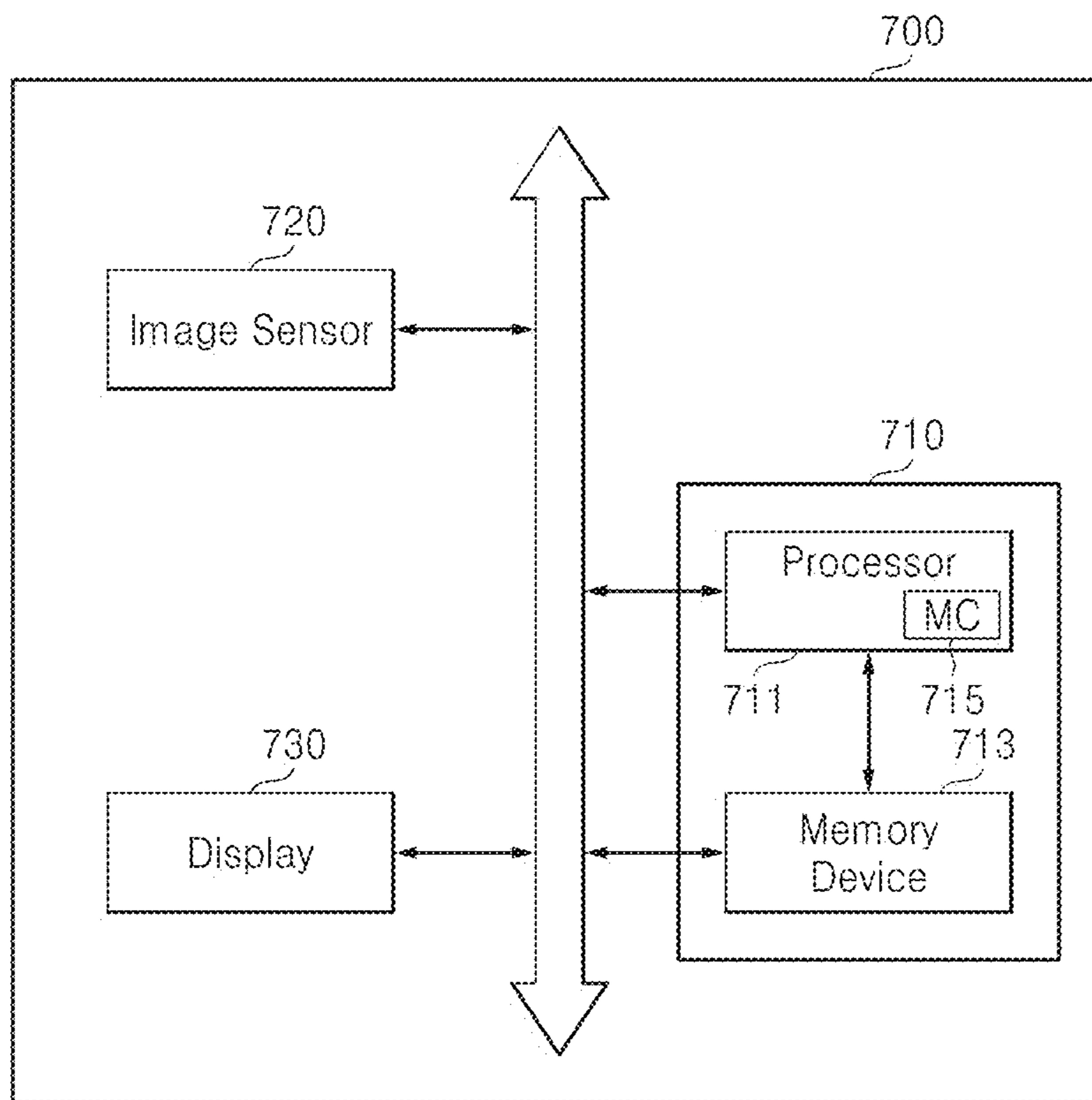


FIG. 17

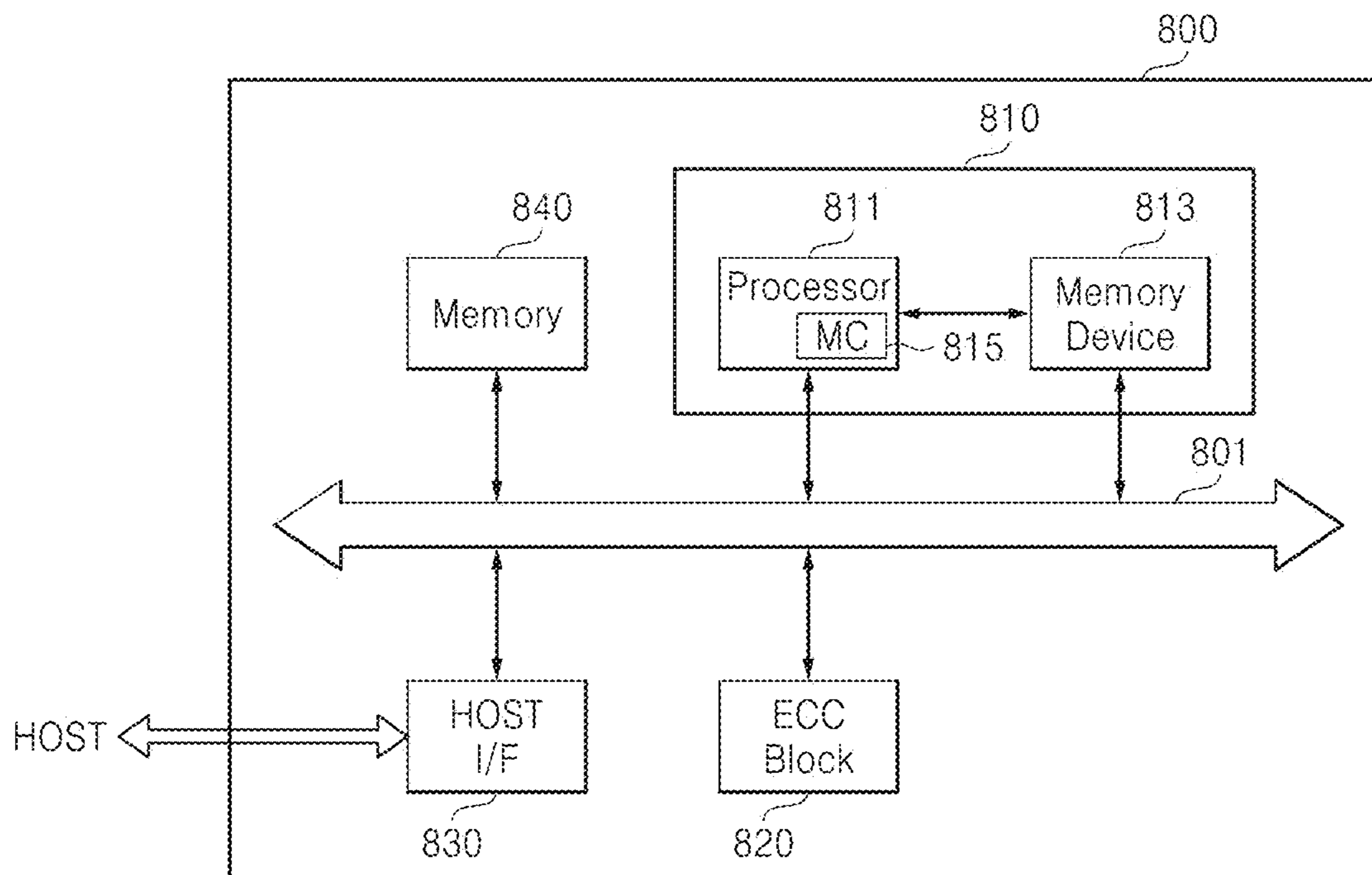
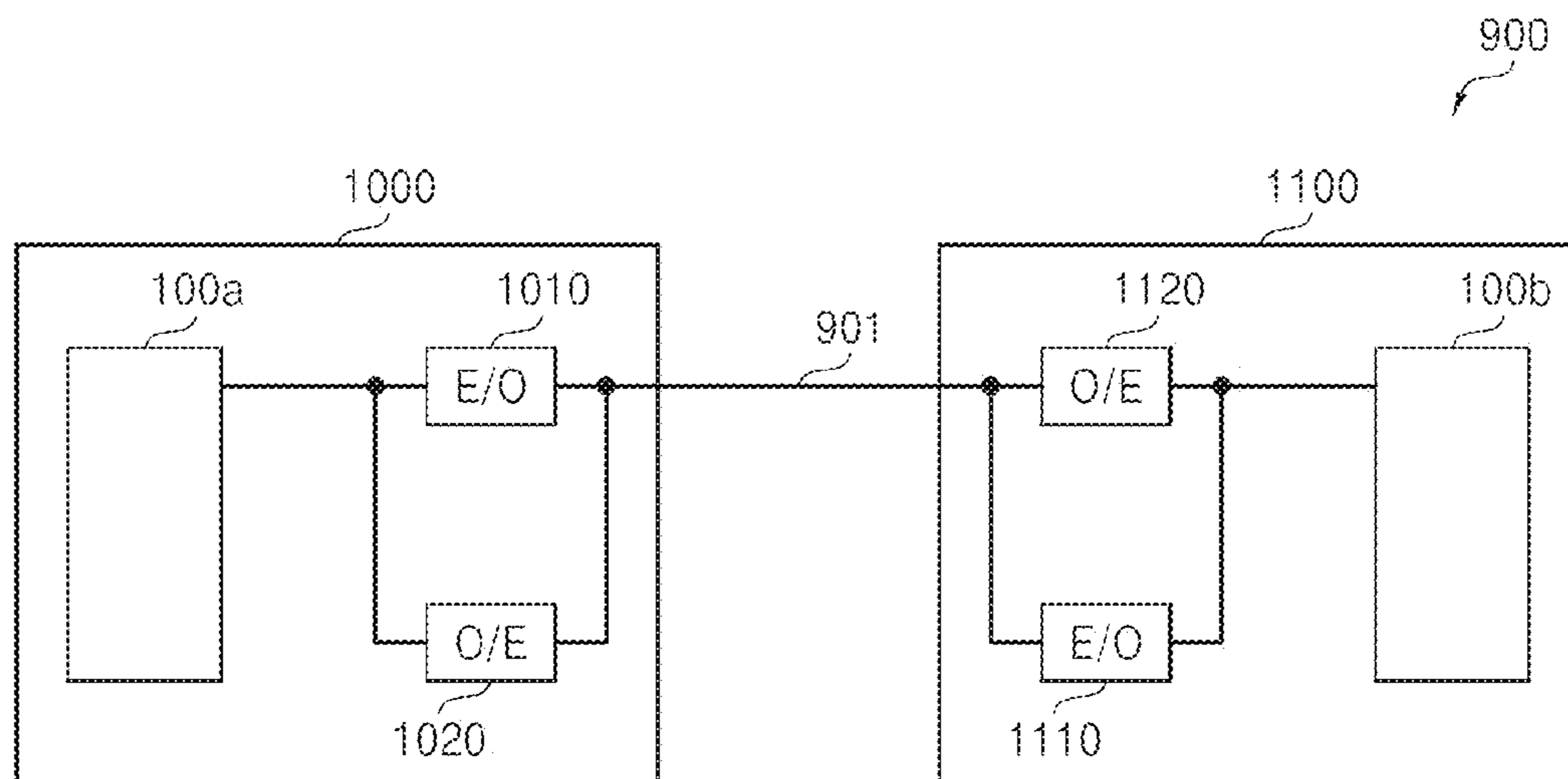


FIG. 18



MEMORY CONTROLLER AND METHOD OF OPERATING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

A claim for priority under 35 U.S.C. §119 is made to Korean Patent Application No. 10-2013-0028056, filed on Mar. 15, 2013, in the Korean Intellectual Property Office, the entire contents of which are hereby incorporated by reference

BACKGROUND

Embodiments of the inventive concept relate to a memory controller and a method of operating the same, and more particularly, to a memory controller that reduces data loss and a method of operating the same.

A memory device includes memory cells that store data. To enable a system including the memory device to operate normally, errors in the data need to be minimized. The memory device may include component(s) for correcting errors in data. When the memory cells are densely formed in a small area, data loss may occur due to interference between memory cells in which data are stored.

SUMMARY

According to embodiments of the inventive concept, there is provided a method of operating a memory controller. The method includes determining a data state based on an input stream including multiple alphabet letters; converting a part of the input stream, which corresponds to a conversion size, into alphabet letters in a lower numeral system when the data state is determined to be a first state among multiple predetermined data states; inserting one of the converted alphabet letters into the input stream; and outputting each of the alphabet letters in the input stream as it is when the data state is determined to be a second state among the predetermined data states.

The method may further include determining whether the one converted alphabet letter can be output in the data state determined based on the input stream; and mapping the one converted alphabet letter to a different alphabet letter according to a determination result.

The method may further include storing the converted alphabet letters in a first sub buffer. The part of the input stream is converted into the alphabet letters in the lower numeral system when the first sub buffer is empty. The method may further include sequentially inserting converted alphabet letters remaining in the first sub buffer into the input stream when reception of the input stream is completed.

The method may further include determining a data state based on read data including alphabet letters, restoring a part of the read data to a higher numeral system, and inserting the restored part into the read data. The method may also include mapping each of the alphabet letters in the read data to a different alphabet letter according to the data state determined based on the read data. A size of the restored part of the read data may be the conversion size.

The first state may be a data state in which at least one of the alphabet letters cannot be output. The second state may be a data state in which all of the alphabet letters can be output. The conversion size may be determined depending on a size of the input stream.

According to other embodiments of the inventive concept, there is provided a memory controller including a pattern transformer and a pattern de-transformer. The pattern trans-

former is configured to convert a part of an input stream including multiple alphabet letters from a higher numeral system to a lower numeral system when a data state is determined to be a first state among multiple predetermined data states based on the input stream, and to insert the converted part into the input stream. The pattern de-transformer is configured to convert a part of read data including multiple alphabet letters to the higher numeral system when a data state is determined to be the first state based on the read data, and to insert the converted part into the read data, the read data being obtained by reading the input stream that has been written to a memory device. The first state is a data state in which at least one of the alphabet letters cannot be output.

The pattern transformer may include a first base converter configured to convert the part of the input stream into the lower numeral system; a first sub buffer configured to store the converted part; a first mapper configured to map an alphabet letter in the converted part to a different alphabet letter when the alphabet letter in the converted part cannot be output in the first state; a first main buffer configured to store the input stream and a mapped alphabet letter; and a first finite state machine configured to determine the data state based on the input stream and the mapped alphabet letter, and to control the first main buffer and the first mapper. The part of the input stream may have a conversion size.

The pattern de-transformer may include a second mapper configured to map each of the alphabet letters in the read data to a different alphabet letter according to the data state determined based on the read data; a second sub buffer configured to store the mapped alphabet letters; a second base converter configured to restore alphabet letters to the higher numeral system from the mapped alphabet letters; a second main buffer configured to store the read data and the restored alphabet letters; and a second finite state machine configured to determine the data state based on the read data, and to control the second main buffer and the second mapper. The number of restored alphabet letters may be the same as the conversion size.

The conversion size may be determined depending on a size of the input stream.

According to further embodiments of the inventive concept, there is provided a memory system including the above-described memory controller, and a memory device configured to write the input stream from the memory controller and to read the input stream under control of the memory controller, and to output a read input stream as the read data.

According to other embodiments of the inventive concept, there is provided a memory device including a memory cell array and a memory controller. The memory cell array includes multiple multi-level memory cells for storing at least one of binary, ternary or quaternary data, and a memory controller for converting an input stream received from a host to provide write data that is stored in the memory device, and for converting read data received from the memory device to provide an output stream to the host, the read data corresponding to the stored write data. The memory controller is configured to convert a part of the input stream comprising multiple alphabet letters from a higher numeral system to a lower numeral system when a data state is determined to be a first state among multiple predetermined data states, and to insert the converted part into the input stream to provide the write data. The memory controller is further configured to convert a part of the read data including alphabet letters from the lower numeral system to the higher numeral system when a data state is determined to be the first state based on the read data, and to insert the converted part into the read data to provide the output stream.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages will become apparent from the following description of various embodiments with reference to the attached drawings, in which:

FIG. 1 is a block diagram of an electronic system, according to embodiments of the inventive concept;

FIG. 2 is a block diagram of a pattern transformer illustrated in FIG. 1, according to an embodiment of the inventive concept;

FIG. 3 is a block diagram of a pattern de-transformer illustrated in FIG. 1, according to an embodiment of the inventive concept;

FIG. 4 is a diagram of a data state graph on which a first finite state machine (FSM) illustrated in FIG. 2 and a second FSM illustrated in FIG. 3 base determination of a data state, according to an embodiment of the inventive concept;

FIG. 5 is a diagram of a data state graph on which the first FSM illustrated in FIG. 2 and the second FSM illustrated in FIG. 3 base determination of a data state, according to an embodiment of the inventive concept;

FIG. 6 is a diagram of a data state graph on which the first FSM illustrated in FIG. 2 and the second FSM illustrated in FIG. 3 base determination of a data state, according to an embodiment of the inventive concept;

FIG. 7 is a diagram for explaining operations of a first mapper and a second mapper when the data state is determined based on the data state graph illustrated in FIG. 4, according to an embodiment of the inventive concept;

FIG. 8 is a diagram for explaining operations of a first mapper and a second mapper when the data state is determined based on the data state graph illustrated in FIG. 5, according to an embodiment of the inventive concept;

FIG. 9 is a diagram for explaining operations of a first mapper and a second mapper when the data state is determined based on the data state graph illustrated in FIG. 6, according to an embodiment of the inventive concept;

FIGS. 10A through 10C are diagrams for explaining operation of the pattern transformer when the data state is determined based on the data state graph illustrated in FIG. 6, according to an embodiment of the inventive concept;

FIG. 11 is a flowchart of operations of the pattern transformer illustrated in FIG. 2, according to an embodiment of the inventive concept;

FIG. 12 is a flowchart of operations of the pattern de-transformer illustrated in FIG. 3, according to an embodiment of the inventive concept;

FIG. 13 is a block diagram of a system including an example of the memory system of FIG. 1, according to an embodiment of the inventive concept;

FIG. 14 is a block diagram of a system including an example of the memory system of FIG. 1, according to another embodiment of the inventive concept;

FIG. 15 is a block diagram of a system including an example of the memory system of FIG. 1, according to another embodiment of the inventive concept;

FIG. 16 is a block diagram of a system including an example of the memory system of FIG. 1, according to another embodiment of the inventive concept;

FIG. 17 is a block diagram of a system including an example of the memory system of FIG. 1, according to another embodiment of the inventive concept; and

FIG. 18 is a block diagram of a system including an example of the memory system of FIG. 1, according to another embodiment of the inventive concept.

DETAILED DESCRIPTION OF THE EMBODIMENTS

Embodiments will be described in detail with reference to the accompanying drawings. The inventive concept, however, may be embodied in various different forms, and should not be construed as being limited only to the illustrated embodiments. Rather, these embodiments are provided as examples so that this disclosure will be thorough and complete, and will fully convey the concept of the inventive concept to those skilled in the art. Accordingly, known processes, elements, and techniques are not described with respect to some of the embodiments of the inventive concept. Unless otherwise noted, like reference numerals denote like elements throughout the attached drawings and written description, and thus descriptions will not be repeated. In the drawings, the sizes and relative sizes of layers and regions may be exaggerated for clarity.

It will be understood that when an element is referred to as being “connected” or “coupled” to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being “directly connected” or “directly coupled” to another element, there are no intervening elements present. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items and may be abbreviated as “/”.

It will be understood that, although the terms first, second, etc., may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first signal could be termed a second signal, and similarly, a second signal could be termed a first signal without departing from the scope of the present teachings.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the inventive concept. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” or “includes” and/or “including” when used in this specification, specify the presence of stated features, regions, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, regions, integers, steps, operations, elements, components, and/or groups thereof. The term “exemplary” refers to an illustration or example.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and/or the present application, and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

FIG. 1 is a block diagram of an electronic system 10, according to an embodiment of the inventive concept. The electronic system 10 may be implemented as an electronic device or a portable device, such as a mobile telephone, a smart phone, a tablet personal computer (PC), a personal digital assistant (PDA), an enterprise digital assistant (EDA), a digital still camera, a digital video camera, a portable multimedia player (PMP), a personal navigation device or portable navigation device (PND), a handheld game console, or

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an e-book, for example. The electronic system **10** includes a host **50** and a memory system **100**.

The host **50** may include a processor, a display, and an input device for the operation of the electronic system **10**. The host **50** may transmit data to and receive data from the memory system **100**. When necessary, the host **50** may store data in the memory system **100** or fetch data from the memory system **100**.

The memory system **100** is configured to exchange data in stream format with the host **50**. In other words, the memory system **100** may receive an input stream IS from the host **50** and transmit an output stream OS to the host **50**. The memory system **100** includes a memory device **150** and a memory controller **200**.

The memory device **150** may include a memory cell array (not shown), a read/write circuit (not shown), and control logic (not shown). The memory cell array may include a plurality of memory cells that store data. The memory cells may store data using voltage level differences for binary, ternary or quaternary data, for example. In other words, the memory cells may be multi-level cells (MLCs).

The memory cells may be implemented as non-volatile memory cells that retain stored data even when not powered, or volatile memory cells that retain data only when powered. Data may be stored in the memory cells by physically cutting a fuse using a laser or by electrically programming, for example. The memory cells may be dynamic random access memory (DRAM) cells, static RAM (SRAM) cells, electrically erasable programmable read-only memory (EEPROM) cells, flash memory cells, magnetic RAM (MRAM) cells, conductive bridging RAM (CBRAM) cells, ferroelectric RAM (FeRAM) cells, phase-change RAM (PRAM) cells, or resistive RAM (RRAM or ReRAM) cells, for example, although other types of memory cells may be incorporated without departing from the scope of the present teachings. The, the memory cell array may be implemented in two or three dimensions.

The read/write circuit may read data from or write data to an address in the memory cell array according to an address signal and a command, which are received from the memory controller **200**. The control logic controls the overall operation of the memory device **150**.

The memory controller **200** generates address signals and commands for controlling operation of the memory device **150**. The memory controller **200** is configured to convert the input stream IS into write data WD and to convert read data RD into the output stream OS. For purposes of illustration, the read data RD corresponds to the write data WD written in the memory device **150**. In the depicted embodiment, the memory controller **200** includes a pattern transformer **210**, a pattern de-transformer **230**, an error correction code (ECC) encoder **260**, and an ECC decoder **270**.

The pattern transformer **210** receives the input stream IS from the host **50** and transforms the input stream IS to avoid forbidden pattern(s) in the input stream IS, as needed. When the memory cells included in the memory cell array are MLCs, each of the memory cells has multiple threshold voltage distribution states respectively corresponding to multiple levels. The threshold voltage distribution of each of the states may be wider than a desired window due to various factors. For instance, the threshold voltage distribution may be wider due to coupling (e.g., F-poly coupling) between adjacent memory cells during a program operation. Due to such coupling, it may fail to read data from a memory cell. In particular, coupling may be worse when a particular data pattern, i.e., a forbidden pattern (e.g., P3-E-P3) included in the read data RD is stored across adjacent memory cells.

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The pattern de-transformer **230** restores the forbidden pattern(s) in the decoded read data RD received from the ECC decoder **270**, and outputs the output stream OS. The ECC encoder **260** encodes the transformed input stream IS received from the pattern transformer **210** and outputs the write data WD. The ECC decoder **270** decodes the read data RD received from the memory device **150** and outputs the decoded read data RD, for detecting and correcting errors.

FIG. 2 is a block diagram of the pattern transformer **210** illustrated in FIG. 1, according to an embodiment of the inventive concept. Referring to FIGS. 1 and 2, the pattern transformer **210** includes a first main buffer **212**, a first finite state machine (FSM) **214**, a first sub buffer **216**, a first base converter **218**, and a first mapper **220**.

The first main buffer **212** temporarily stores the input stream IS received from the host **50**. When the first sub buffer **216** is empty, the first main buffer **212** transmits a part of an “alphabet” (e.g., a set or string of “letters,” which may be alphanumeric symbols or digits, for example) included in the input stream IS to the first sub buffer **216** under control of the first FSM **214**. Here, the part of the alphabet transmitted to the first sub buffer **214** may have a size corresponding to a conversion size (e.g., number of letters converted to another numeral system). For instance, when the conversion size is ten, the part of the alphabet transmitted to the first sub buffer **214** may be made up of ten letters. An illustrative method of determining the conversion size will be described below with reference to FIG. 6.

The first main buffer **212** receives at least one alphabet letter mapped (referred to as “at least one mapped alphabet letter”) from the first mapper **220**, and inserts the at least one alphabet letter into the input stream IS under control of the first FSM **214**. After receiving all of the input stream IS from the host **50**, the first main buffer **212** receives at least one base-converted alphabet letter remaining in the first sub buffer **216** through the first mapper **220**, and inserts the at least one base-converted alphabet letter into the input stream IS at the end of the input stream IS under control of the first FSM **214**. The first main buffer **212** transmits the input stream IS to the ECC encoder **260** under control of the first FSM **214**.

The first FSM **214** determines a data state (e.g., S1, S2, S3, or S4) based on the input stream IS temporarily stored in the first main buffer **212** or the at least one mapped alphabet letter. The first FSM **214** controls the first main buffer **212** and/or the first mapper **220** according to the data state that has been determined. The determination of the data state and the control operation of the first FSM **214** will be described below with reference to FIGS. 4 through 10C.

The first sub buffer **216** temporarily stores the part of the alphabet included in the input stream IS, which is received from the first main buffer **212**, and then transmits it to the first base converter **218**. In addition, the first sub buffer **216** temporarily stores base-converted alphabet letters received from the first base converter **218** and then transmits them to the first mapper **220**.

The first base converter **218** receives the part of the alphabet included in the input stream IS, and converts it into letters of an alphabet in a lower numeral system. For instance, the first base converter **218** may receive a string of “3000” in a quaternary numeral system (base-4) and convert it into a string of “21010” in a ternary numeral system (base-3). The first base converter **218** transmits the base-converted alphabet letters to the first sub buffer **216**.

When the base-converted alphabet letters received from the first sub buffer **216** cannot be output in a current data state, the first mapper **220** maps the base-converted alphabet letters to different alphabet letters under control of the first FSM **214**.

When the base-converted alphabet letters received from the first sub buffer **216** can be output in the current data state, the first mapper **220** maps the base-converted alphabet letters to the same alphabet letters under control of the first FSM **214**. For instance, the first mapper **220** may map a base-converted alphabet letter “2” to the same alphabet letter “2” and map a base-converted alphabet letter “1” to a different alphabet letter, such as “0.” The first mapper **220** transmits the mapped alphabet letter to the first main buffer **212**.

FIG. **3** is a block diagram of the pattern de-transformer **230** illustrated in FIG. **1**, according to an embodiment of the inventive concept. Referring to FIGS. **1** through **3**, the pattern de-transformer **230** includes a second main buffer **232**, a second FSM **234**, a second mapper **236**, a second sub buffer **238**, and a second base converter **240**.

The second main buffer **232** temporarily stores the decoded read data RD received from the ECC decoder **270**. The second main buffer **232** transmits at least one alphabet letter of an alphabet included in the decoded read data RD to the second mapper **236** under control of the second FSM **234**.

When the second sub buffer **238** is empty, the second main buffer **232** sequentially receives and temporarily stores the decoded read data RD with a space corresponding to the conversion size being empty under control of the second FSM **234**, while transmitting the at least one alphabet letter to the second mapper **236**. The second main buffer **232** receives base-restored alphabet letters from the second sub buffer **238** and inserts them into the empty space. The second main buffer **232** transmits the restored read data RD to the host **50** as the output stream OS.

The second FSM **234** determines a data state (e.g., S1, S2, S3, or S4) according to the decoded read data RD temporarily stored in the second main buffer **232**. The second FSM **234** controls the second main buffer **232** and/or the second mapper **236** according to the determined data state. The determination of the data state and the control operation of the second FSM **234** will be described in detail below with reference to FIGS. **4** through **10C**.

The second mapper **236** may map the at least one alphabet letter received from the second main buffer **232** to a different alphabet letter under control of the second FSM **234**. For instance, the second mapper **236** may map the at least one alphabet letter “1” to a different alphabet letter “2” and map “0” to “1.”

The second mapper **236** performs reverse mapping to the mapping performed by the first mapper **220** illustrated in FIG. **2** in the same data state. For instance, when the first mapper **220** maps “2” to “3” in the data state S4 as shown in FIG. **6**, the second mapper **236** maps “3” to “2.” For this operation, the first and second FSMs **214** and **234** may share mapping information with respect to the data states. The second mapper **236** transmits the at least one mapped alphabet letter to the second sub buffer **238**.

The second sub buffer **238** temporarily stores the at least one mapped alphabet letter received from the second mapper **236**, and then transmits the at least one mapped alphabet letter to the second base converter **240**. In addition, the second sub buffer **238** also temporarily stores base-restored alphabet letters received from the second base converter **240** and then transmits them to the second main buffer **232**.

The second base converter **240** receives the at least one mapped alphabet letter. When the second base converter **240** receives as many alphabet letters as a size of a string into which a string of alphabet letters corresponding to the conversion size is converted (for example, 24 letters of the ternary numeral system into which 19 letters corresponding to a conversion size of 19 in the quaternary numeral system are

converted), the second base converter **240** may restore alphabet letters in a higher numeral system from the letters of a current numeral system. For instance, the second base converter **240** may receive “21010” in the ternary number system and restore “3000” over the quaternary numeral system. The second base converter **240** transmits the base-restored alphabet letters to the second sub buffer **238**.

FIG. **4** is a diagram of a data state graph based on which the first FSM **214** illustrated in FIG. **2** and the second FSM **234** illustrated in FIG. **3** determine a data state, according to embodiments of the inventive concept. FIG. **5** is a diagram of a data state graph based on which the first FSM **214** and the second FSM **234** determine a data state, according to other embodiments of the inventive concept. FIG. **6** is a diagram of a data state graph based on which the first FSM **214** and the second FSM **234** determine a data state, according to other embodiments of the inventive concept.

Referring to FIGS. **4** through **6**, the first FSM **214** and the second FSM **234** determine a data state. In the exemplary embodiments illustrated in FIGS. **4** through **6**, it is assumed that the pattern transformer **210** and the pattern de-transformer **230** receive and process quaternary data in the quaternary numeral system. For the sake of convenience of explanation, operation of only the first FSM **214** with respect to the data state will be described, although the description likewise applies to the operation of the FSM **234**.

FIG. **4** illustrates the data state graph for avoiding a forbidden pattern of 3-0-3. Here, S1, S2, and S3 denote data states. Each of the data states S1 through S3 may be shifted to another data state according to the input stream IS temporarily stored in the first main buffer **212** or a mapped alphabet letter 0, 1, 2, or 3.

When the data state is S1 and the alphabet letter stored in the first main buffer **212** is 0, 1, or 2, the data state remains in S1. When data state is S1 and the alphabet letter stored in the first main buffer **212** is 3, the data state is shifted from S1 to S2. When the data state is S2 and the alphabet letter stored in the first main buffer **212** is 1 or 2, the data state is shifted from S2 to S1. When the data state is S2 and the alphabet letter stored in the first main buffer **212** is 3, the data state remains in S2. When the data state is S2 and the alphabet letter stored in the first main buffer **212** is 0, the data state is shifted from S2 to S3. When the data state is S3 and the alphabet letter stored in the first main buffer **212** is 0, 1, or 2, the data state is shifted from S3 to S1.

Consequently, when the data state is S3, the alphabet letter stored in the first main buffer **212** cannot be 3. This is to avoid the forbidden pattern of 3-0-3. In other words, S3 may be defined as a “first state” in which at least one alphabet letter (e.g., “3” in the depicted example) among a plurality of alphabet letters “0”, “1”, “2”, and “3” cannot be output according to the input stream IS including the alphabet letters “0”, “1”, “2”, and “3” or the mapped alphabet letters. S1 and S2 may be defined as a “second state” in which all of the alphabet letters (e.g., “0”, “1”, “2”, and “3” in the depicted example) can be output according to the input stream IS including the alphabet letters “0”, “1”, “2”, and “3” or the mapped alphabet letters.

When a current data state is shifted to the first state according to the alphabet letters included in the input stream IS, the first FSM **214** controls the first base converter **218** to convert a part corresponding to a conversion size in the input stream IS into a string over a lower numeral system and to insert the string into the input stream IS. When there is a base-converted alphabet letter in the first sub buffer **216**, the first main buffer **212** receives the base-converted alphabet letter from the first sub buffer **216** through the first mapper **220** and inserts the base-converted alphabet letter into the input stream IS under

control of the first FSM 214. When the base-converted alphabet letter cannot be output in a current data state, the first FSM 214 controls the first mapper 220 to map the base-converted alphabet letter to another alphabet letter.

When the current data state is shifted to the second state according to the input stream IS or the mapped alphabet letters, the first FSM 214 controls the first main buffer 212 to output the alphabet letter as it is.

FIG. 5 illustrates the data state graph for avoiding a forbidden pattern of 2-2. Here, S1 and S2 denote data states. Each of the data states S1 and S2 may be shifted to another data state according to the input stream IS temporarily stored in the first main buffer 212 or a base-converted alphabet letter 0, 1, 2, or 3.

When the data state is S1 and the alphabet letter stored in the first main buffer 212 is 0, 1, or 3, the data state remains in S1. When the data state is S1 and the alphabet letter stored in the first main buffer 212 is 2, the data state is shifted from S1 to S2. When the data state is S2 and the alphabet letter stored in the first main buffer 212 is 0, 1, or 3, the data state is shifted from S2 to S1.

Consequently, the alphabet letter stored in the first main buffer 212 when the data state is S2 cannot be 2. This is to avoid the forbidden pattern of 2-2. Accordingly, the data state S1 corresponds to the second state and the data state S2 corresponds to the first state. The control operation of the first FSM 214 in the embodiments illustrated in FIG. 5 is substantially the same as that described above with reference to FIG. 4. Thus, descriptions thereof will not be repeated.

FIG. 6 illustrates the data state graph for avoiding the forbidden patterns of 3-0-3 and 2-2. Thus, the data state graph illustrated in FIG. 6 is essentially a combination of the content of the data state graph illustrated FIG. 4 and the content of the data state graph illustrated in FIG. 5.

In FIG. 6, S3 and S4 correspond to the first state and S1 and S2 correspond to the second state. The control operation of the first FSM 214 in the embodiments illustrated in FIG. 6 is substantially the same as that described above with reference to FIGS. 4 and 5. Thus, descriptions thereof will not be repeated.

When the first FSM 214 operates according to the data state graph illustrated in FIG. 6, a method by which the first FSM 214 determines a conversion size of the part of the input stream IS that will be converted into a string in a lower numeral system by the first base converter 218 will be described below. This method may also be used in the embodiments illustrated in FIGS. 4 and 5.

An adjacent matrix of the data state graph illustrated in FIG. 6 may be expressed by Equation (1):

$$A = \begin{bmatrix} 2 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 \\ 2 & 0 & 0 & 1 \\ 2 & 1 & 0 & 0 \end{bmatrix} \quad (1)$$

Each of the rows and columns of the adjacent matrix corresponds to a data state. A value of an element defined by a particular row and a particular column denotes the number of alphabet letters that can be moved from a data state corresponding to the row to a data state corresponding to the column. For instance, the value “2” of the element a_{11} in the first row and the first column denotes the number of alphabet letters “0” and “1” that can be moved from the data state S1 to the data state S1. The value “1” of the element a_{34} in the third

row and the fourth column denotes the number of alphabet letter “2” that can be moved from the data state S3 to the data state S4.

A probability-transition matrix obtained when a probability is considered in the adjacent matrix of the data state graph illustrated in FIG. 6 may be expressed by Equation (2):

$$Q = \begin{bmatrix} 2/4 & 1/4 & 0 & 1/4 \\ 1/4 & 1/4 & 1/4 & 1/4 \\ 2/3 & 0 & 0 & 1/3 \\ 2/3 & 1/3 & 0 & 0 \end{bmatrix} \quad (2)$$

Each of the rows and columns of the probability-transition matrix corresponds to a data state. A value of an element defined by a particular row and a particular column denotes a ratio of the number of alphabet letters that can be moved from a data state corresponding to the row to a data state corresponding to the column to the total number of alphabet letters that can be moved from the data state corresponding to the row to any one of the data states. For instance, the value “2/4” of the element q_{11} in the first row and the first column denotes the ratio of the number of alphabet letters “0” and “1” that can be moved from the data state S1 to the data state S1 to the total number of alphabet letters “0”, “1”, “2”, and “3” that can be moved from the data state S1 to any one of the data states S1 through S4. The value “1/3” of the element q_{34} in the third row and the fourth column denotes the ratio of the number of alphabet letters “2” that can be moved from the data state S3 to the data state S4 to the total number of alphabet letters “0”, “1”, and “2” that can be moved from the data state S3 to any one of the data states S1 through S4.

When a stationary probability vector giving $\pi Q = \pi$ is obtained with respect to the probability-transition matrix Q, π is defined as Equation (3):

$$\pi = [P1, P2, P3, P4] = \left[\frac{92}{191}, \frac{48}{191}, \frac{12}{191}, \frac{39}{191} \right] \quad (3)$$

Each element of the stationary probability vector indicates a probability of the occurrence of a data state with no consideration of a previous data state. In other words, when the previous data state is not considered, a probability P1, P2, P3, or P4 of the occurrence of each of the data states S1, S2, S3, and S4 is 92/191, 48/191, 12/191, and 39/191, respectively.

A conversion size k_j may be expressed by Equation (4):

$$k_j = N \frac{q_j \log_m j}{\sum_{i=2}^m q_i \log_m i} \quad (4)$$

In Equation (4), N is the total size (e.g., 10,000 when the input stream IS is 10,000 bits in length) of the input stream IS, “m” is a value (e.g., 4 when the input stream IS is quaternary data) corresponding to a numeral system in which the input stream IS is represented, “j” is a value (e.g., 3) corresponding to a numeral system (e.g., a ternary numeral system when the input stream IS is quaternary data) into which the input stream IS is converted, and “i” is at least 2 and does not exceed (m-1).

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In Equation 4, q_j may be defined as Equation (5):

$$q_j = \sum_{v \in V, |S_v|=j} P_v \quad (5)$$

In Equation (5), V is a set of serial numbers respectively corresponding to all data states, “ v ” is a number (e.g., 1, 2, 3, or 4 in FIG. 6) corresponding to each of the data states, i.e., an element of the set V , $|S_v|$ is the maximum number of alphabet letters that can be output in a current data state. For instance, when $j=3$ as shown in FIG. 6, q_3 is the sum of the elements of the stationary probability vector giving $|S_v|=3$, i.e., $12/191 + 39/191 = 51/191$.

When $N=10,000$, $j=3$ as shown in FIG. 6, and $m=4$ in Equation (4), k_3 can be calculated as shown in Equation (6):

$$k_3 = 10000 * \frac{\left(\frac{12}{191} + \frac{39}{191} \right) * \log_4 3}{\left(\frac{92}{191} * \log_4 4 + \frac{48}{191} * \log_4 4 + \frac{12}{191} * \log_4 3 + \frac{39}{191} * \log_4 3 \right)} \quad (6)$$

Consequently, k_3 is 2240.18 (that is about 2241). This means that the first base converter **218** performs base conversion on 2241 alphabet letters. The first base converter **218** may convert 2241 alphabet letters at once or over several times.

The total number of alphabet letters finally output from the pattern transformer **210** through the base conversion of the first base converter **218** may be calculated using Equation (7):

$$N_o = N \frac{1}{\sum_{i=2}^m q_i \log_m i} \quad (7)$$

In the above-described example, the total number of alphabet letters output from the pattern transformer **210** is 10586.6 (that is, about 10587). This agrees with the number of alphabet letters when the first base converter **218** converts 2241 letters from the quaternary numeral system into ternary numeral system. The number of ternary numeral system alphabet letters is 2827 and an increment in the number of alphabet letters is 587 (that is, 2827-2241). In other words, an increment in the number of alphabet letters through the operation for avoiding a forbidden pattern is about 587.

FIG. 7 is a diagram for explaining operations of the first mapper **220** and the second mapper **236** when the data state is determined based on the data state graph illustrated in FIG. 4, for example. FIG. 8 is a diagram for explaining operations of the first mapper **220** and the second mapper **236** when the data state is determined based on the data state graph illustrated in FIG. 5, for example. FIG. 9 is a diagram for explaining operations of the first mapper **220** and the second mapper **236** when the data state is determined based on the data state graph illustrated in FIG. 6, for example.

Referring to FIGS. 7 through 9, when the first FSM **214** determines that the data state is the first state, the first FSM **214** receives a base-converted alphabet letter from the first sub buffer **216** and inserts it into the input stream IS. At this time, when the base-converted alphabet letter is a letter that cannot be output in the current data state, the first FSM **214** controls the first mapper **220** to map the base-converted alphabet letter to a different alphabet letter. However, when

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the base-converted alphabet letter is a letter that can be output in the current data state, the first FSM **214** controls the first mapper **220** to map the base-converted alphabet letter to the same alphabet letter.

Referring to FIG. 7, the first mapper **220** does not map the base-converted alphabet letter to a different alphabet letter in the data state S3 corresponding to the first state. In other words, since no base-converted alphabet letter is 3, the first mapper **220** does not need to map the base-converted alphabet letter to a different alphabet letter to avoid the forbidden pattern of 3-0-3.

Differently, referring to FIG. 8, when the base-converted alphabet letter is 2 in the data state S2 corresponding to the first state, the first mapper **220** may map 2 to 3 in order to avoid the forbidden pattern of 2-2. In other words, since the pattern transformer **210** cannot output the alphabet letter 2 in the data state S2, the first mapper **220** maps the alphabet letter 2 to the alphabet letter 3 to avoid the forbidden pattern of 2-2.

Referring to FIG. 9, when the base-converted alphabet letter is 2 in the data state S4 corresponding to the first state, the first mapper **220** may map 2 to 3. In other words, since the pattern transformer **210** cannot output the alphabet letter 2 in the data state S4, the first mapper **220** maps the alphabet letter 2 to the alphabet letter 3 to avoid the forbidden pattern of 2-2.

The second mapper **236** included in the pattern de-transformer **230** may perform reverse mapping to the mapping performed by the first mapper **220** described above with reference to FIGS. 7 through 9. In other words, when the first mapper **220** maps the base-converted alphabet letter to the same alphabet letter (e.g., 2 to 2), the second mapper **236** also maps the base-converted alphabet letter to the same alphabet letter. However, when the first mapper **220** maps the base-converted alphabet letter to a different alphabet letter (e.g., 2 to 3), the second mapper **236** performs reverse mapping (e.g., 3 to 2).

FIGS. 10A through 10C are diagrams for explaining operation of the pattern transformer **210** when the data state is determined based on the data state graph illustrated in FIG. 6, for example. Referring to FIGS. 1 through 3, FIGS. 6 and 9, and FIGS. 10A through 10C, an input time is a time at which each of alphabet letters (i.e., input alphabet letters) included in the input stream IS is input from the host **50** into the pattern transformer **210**. The input time may be determined depending on the operating speed of the host **50**. An output time is a time at which the pattern transformer **210** outputs each of the alphabet letters (i.e., output alphabet letters) included in the pattern-transformed input stream IS. The output time may be determined by control logic (not shown) included in the memory controller **200**.

An output time may come after an input time in the same place as the output time in a sequence and before an input time in the next place in the sequence. For instance, an input alphabet letter of 2 may be input to the pattern transformer **210** at the second input time, and the alphabet letter of 2 may be output from the pattern transformer **210** at the second output time after a predetermined period of time. Thereafter, an input alphabet letter of 3 may be input to the pattern transformer **210** at the third input time.

A pre-output buffer state may indicate the state of the first sub buffer **216** between an input time and an output time in the same place as the input time in the sequence. A post-output buffer state may indicate the state of the first sub buffer **216** between the output time and an input time in the place next to the output time in the sequence.

Referring to FIGS. 10A through 10C, in the exemplary operation of the pattern transformer **210**, the data state is an initial state at the first input time. The initial state may be set

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to a random data state. For instance, the initial state is assumed to be the data state S1, for example.

An alphabet letter of 1 is input to the pattern transformer **210** at the first input time and is temporarily stored in the first main buffer **212**. Since the data state is the second state (S1), the first FSM **214** outputs the alphabet letter of 1 as it is. The first FSM **214** may determine the data state to be S1 based on the alphabet letter of 1.

An alphabet letter of 2 is input to the pattern transformer **210** at the second input time and is temporarily stored in the first main buffer **212**. Since the data state is the second state (S1), the first FSM **214** outputs the alphabet letter of 2 as it is. The first FSM **214** determines the data state to be S4 based on the alphabet letter of 2, as indicated in FIG. 6.

An alphabet letter of 3 is input to the pattern transformer **210** at the third input time and is temporarily stored in the first main buffer **212**. Since the data state is the first state (S4) and there is no alphabet letter in the first sub buffer **216**, a string of alphabet letters corresponding to a conversion size among the alphabet letters included in the input stream IS is transmitted to the first base converter **218**. When the conversion size is 19, for example, the first FSM **214** may transmit 19 alphabet letters respectively input at the third through twenty-first input times to the first base converter **218** through the first sub buffer **216**.

The first base converter **218** converts the 19 quaternary alphabet letters (i.e., 3, 0, 3, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0) into 24 ternary alphabet letters (i.e., 2, 0, 2, 2, 2, 1, 1, 0, 1, 1, 1, 1, 2, 0, 0, 0, 1, 2, 0, 0, 2, 1, 2, 0). The 24 ternary alphabet letters are stored in the first sub buffer **216**, and the first alphabet letter 2 is transmitted to the first mapper **220**.

Since the base-converted alphabet letter 2 cannot be output in the current data state S4, the first FSM **214** controls the first mapper **220** to map 2 to 3, for example. The first mapper **220** outputs the alphabet letter 3, and the first FSM **214** determines the data state to be S2 based on the alphabet letter 3 stored in the first main buffer **212**.

An alphabet letter of 0 is input to the pattern transformer **210** at the twenty-second input time and is temporarily stored in the first main buffer **212**. Since the data state is the second state, the first FSM **214** outputs the alphabet letter 0 as it is. The first FSM **214** determines the data state to be S3 based on the alphabet letter 0.

Twenty-three ternary alphabet letters (i.e., 0, 2, 2, 2, 1, 1, 0, 1, 1, 1, 1, 2, 0, 0, 0, 1, 2, 0, 0, 2, 1, 2, 0) are in the first sub buffer **216**, and the first alphabet letter 0 is transmitted to the first mapper **220**. Since the base-converted alphabet letter 0 can be output in the current data state S3, the first FSM **214** controls the first mapper **220** to map 0 to 0. The first mapper **220** outputs the alphabet letter 0, and the first FSM **214** determines the data state to be S1 based on the alphabet letter 0 stored in the first main buffer **212**.

Alphabet letters input to the pattern transformer **210** at the twenty-third through twenty-fifth input times are 0, 3, and 1, and therefore the data state is not converted to the first state. As a result, the input alphabet letters 0, 3, and 1 are output unchanged.

An alphabet letter of 2 is input to the pattern transformer **210** at the twenty-sixth input time and is temporarily stored in the first main buffer **212**. Since the data state is the second state (S1), the first FSM **214** outputs the alphabet letter 2 as it is. The first FSM **214** determines the data state to be S4 based on the alphabet letter 2.

Twenty-two ternary alphabet letters (i.e., 2, 2, 2, 1, 1, 0, 1, 1, 1, 1, 2, 0, 0, 0, 1, 2, 0, 0, 2, 1, 2, 0) are in the first sub buffer **216** and the first alphabet letter 2 is transmitted to the first mapper **220**. Since the base-converted alphabet letter 2 cannot

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be output in the current data state S4, the first FSM **214** controls the first mapper **220** to map 2 to 3. The first mapper **220** outputs the alphabet letter 3, and the first FSM **214** determines the data state to be S2 based on the alphabet letter 3 stored in the first main buffer **212**.

An alphabet letter input to the pattern transformer **210** at the twenty-seventh input time is 3, and therefore, the data state is not converted to the first state. As a result, the input alphabet letter 3 is output unchanged and the data state is maintained at S2.

An alphabet letter of 0 is input to the pattern transformer **210** at the twenty-eighth input time and is temporarily stored in the first main buffer **212**. Since the data state is the second state (S2), the first FSM **214** output the alphabet letter 0 as it is. The first FSM **214** determines the data state to be S3 based on the alphabet letter 0.

Twenty-one ternary alphabet letters (i.e., 2, 2, 1, 1, 0, 1, 1, 1, 1, 2, 0, 0, 0, 1, 2, 0, 0, 2, 1, 2, 0) are in the first sub buffer **216** and the first alphabet letter 2 is transmitted to the first mapper **220**. Since the base-converted alphabet letter 2 can be output in the current data state S3, the first FSM **214** controls the first mapper **220** to map 2 to 2. The first mapper **220** outputs the alphabet letter 2, and the first FSM **214** determines the data state to be S4 based on the alphabet letter 2 stored in the first main buffer **212**.

Twenty ternary alphabet letters (i.e., 2, 1, 1, 0, 1, 1, 1, 1, 2, 0, 0, 0, 1, 2, 0, 0, 2, 1, 2, 0) are in the first sub buffer **216** and the first alphabet letter 2 is transmitted to the first mapper **220**. Since the base-converted alphabet letter 2 cannot be output in the current data state S4, the first FSM **214** controls the first mapper **220** to map 2 to 3. The first mapper **220** outputs the alphabet letter 3, and the first FSM **214** determines the data state to be S2 based on the alphabet letter 3 stored in the first main buffer **212**.

Thereafter, from the thirtieth input time to the thirty-ninth input time the pattern transformer **210** repeats a procedure for determining the current data state and outputting a pattern-transformed alphabet letter according to the determined data state.

An alphabet letter of 2 is input to the pattern transformer **210** at the fortieth input time and is temporarily stored in the first main buffer **212**. Since the data state is the second state (S1), the first FSM **214** outputs the alphabet letter 2 as it is. The first FSM **214** determines the data state to be S4 based on the alphabet letter 2.

Since there is no input stream IS after the fortieth input time, 14 ternary alphabet letters (i.e., 1, 1, 2, 0, 0, 0, 1, 2, 0, 0, 2, 1, 2, 0) stored in the first sub buffer **216** are sequentially output through the first mapper **220** and the first main buffer **212**.

Although the operation of the pattern transformer **210** only has been described with reference to FIGS. 10A through 10C, since the operation of the pattern de-transformer **230** is performed in reverse order from the operation of the pattern transformer **210**, the description thereof will be omitted.

FIG. 11 is a flowchart of the operations of the pattern transformer **210** illustrated in FIG. 2. Referring to FIGS. 1, 2, 6, 9, 10A through 10C, and 11, the first main buffer **212** receive the input stream IS including a plurality of alphabet letters from the host **50**. The first FSM **214** determines a current data state (e.g., first or second current state) based on a current one of the alphabet letters included in the input stream IS in operation S100.

When the current data state is determined to be the first state (e.g., S3 or S4 in FIG. 6) among a plurality of predetermined data states based on the input stream IS in operation S105, the first FSM **214** determines whether there is any

base-converted alphabet letter in the first sub buffer **216** in operation **S107**. When it is determined that there is no base-converted alphabet letter in the first sub buffer **216** in operation **S107**, the first base converter **218** converts a part of the input stream **IS**, which corresponds to the conversion size, into alphabet letters in a lower numeral system in operation **S110**. When it is determined that there is any base-converted alphabet letter in the first sub buffer **216** in operation **S107**, the process proceeds to operation **S130**, discussed below.

The first sub buffer **216** stores the base-converted alphabet letters received from the first base converter **218** in operation **S120**. The first FSM **214** determines whether one of the base-converted alphabet letters stored in the first sub buffer **216** can be output in the current data state in operation **S130**.

When it is determined that the one base-converted alphabet letter can not be output in the current data state, the first mapper **220** maps the one base-converted alphabet letter to a different alphabet letter in operation **S140**. For instance, when the one base-converted alphabet letter is 2 in the data state **S4** in FIG. 6, the first FSM **214** controls the first mapper **220** to map the alphabet letter 2 to alphabet letter 3. When it is determined that the one base-converted alphabet letter can be output in the current data state, the first mapper **220** maps the one base-converted alphabet letter to the same alphabet letter in operation **S140**. After being mapped, the one base-converted alphabet letter may be inserted by the first main buffer **212** in the input stream **IS** in operation **S150**.

The first FSM **214** determines whether the input stream **IS** has been completely received from the host **50** in operation **S155**. When it is determined that the input stream **IS** has not been completely received in operation **S155**, the pattern transformer **210** returns to operation **S100**. When it is determined that the input stream **IS** has been completely received in operation **S155**, the first FSM **214** sequentially receives and inserts the base-converted alphabet letters remaining in the first sub buffer **216** into the input stream **IS** at the end of the input stream **IS** in operation **S160**.

When the current data state is determined to be the second state (e.g., **S1** or **S2** in FIG. 6) among the plurality of predetermined data states based on the input stream **IS** in operation **S105**, the current alphabet letter in the input stream **IS** may be output as it is in operation **S170**.

FIG. 12 is a flowchart of the operations of the pattern de-transformer **230** illustrated in FIG. 3. Referring to FIGS. 1, 3, 6, 9, and 10A through 12, the second main buffer **232** receives and temporarily stores the read data **RD** including a plurality of alphabet letters **ECC** decoded by the **ECC** decoder **270**. The second FSM **234** determines a current data state based on a current alphabet letter included in the read data **RD** in operation **S200**.

When the second sub buffer **238** is empty, the second main buffer **232** transmits the current alphabet letter to the second mapper **236** and may simultaneously store the next alphabet letter of the read data **RD** with a space corresponding to the conversion size being empty under control of the second FSM **234**. The second FSM **234** controls the alphabet letter received by the second mapper **236** to be mapped to the same or a different alphabet letter based on the current data state and the mapping information shared with the first FSM **214** in operation **S210**.

The second base converter **240** receives mapped alphabet letters one by one until receiving all of alphabet letters in a string, into which a string corresponding to the conversion size has been converted by the first base converter **218** (for example, 24 letters in a string over the ternary alphabet into which 19 letters in a string corresponding to a conversion size of 19 over the quaternary alphabet are converted). The second

base converter **240** restores alphabet letters in a higher numeral system from the received alphabet letters in a lower numeral system in operation **S220**.

The second main buffer **232** receives the restored alphabet letters from the second base converter **240** through the second sub buffer **238**, and inserts restored alphabet letters into the empty space under control of the second FSM **234** in operation **S230**.

Although the description of the operations of the second FSM **234** is simpler than that of the operations of the first FSM **214**, the operations of the second FSM **234** are essentially the reverse of the operations of the first FSM **214**.

FIG. 13 is a block diagram of a system **400** including an example of the memory system **100** of FIG. 1, according to an embodiment of the inventive concept.

Referring to FIGS. 1 and 13, the system **400** may be embodied as an electronic device or a portable device. The portable device may be a cellular phone, a smart phone, or a tablet PC, for example.

The system **400** includes a memory system **410** having a processor **411** and a memory device **413**. The memory device **413** may be implemented as the memory device **150** of FIG. 1, for example. In an embodiment, the processor **411** and the memory device **413** may be packaged in a semiconductor package. In this case, the semiconductor package may be mounted on a system board (not shown).

The processor **411** includes a memory controller **415** configured to control data processing operations (e.g., write operation and/or read operations) of the memory device **413**. The memory controller **415** may be the memory controller **200** of FIG. 1, for example. The memory controller **415** is controlled by the processor **411** configured to control overall operations of the system **400**. In an embodiment, the memory controller **415** may be connected between the processor **411** and the memory device **413**. Data stored in the memory device **413** may be displayed on a display unit **420** under control of the processor **411**.

A radio transceiver **430** may transmit and/or receive radio signals via an antenna **ANT**. For example, the radio transceiver **430** may transform the radio signal received via the antenna **ANT** into a signal to be processed by the processor **411**. Thus, the processor **411** may process a signal output from the radio transceiver **430**, and store the processed signal in the memory device **413** and/or display the processed signal on the display unit **420**. Also, the radio transceiver **430** may transform a signal output from the processor **411** into a radio signal, and output the radio signal to the outside via the antenna **ANT**.

The system **400** further includes an input device **440** by which control signals for controlling operations of the processor **411** and data to be processed by the processor **411** are input. The input device **440** may be embodied as a pointing device, for example, such as a touch pad and a computer mouse, or a keyboard.

The processor **411** may control the display unit **420** to display data output from the memory device **413**, radio signals output from the radio transceiver **430**, and/or data output from the input device **440**. The various components may communicate via a bus.

FIG. 14 is a block diagram of a system **500** including an example of the memory system **100** of FIG. 1, according to another embodiment of the inventive concept. Referring to FIGS. 1 and 14, the system **500** may be embodied as a PC, a tablet PC, a net-book, an e-reader, a personal digital assistant (PDA), a portable multimedia player (PMP), an MP3 player, or an MP4 player, for example.

The system **500** includes a memory system **510** having a processor **511** and a memory device **513**. The processor **511** is configured to control overall operations of the system **500**. The memory device **513** may be implemented as the memory device **150** of FIG. 1, for example. In an embodiment, the memory device **513** may be packaged in a semiconductor package. The semiconductor package may be mounted on a system board (not shown).

The processor **511** may include a memory controller **515** configured to control an operation of the memory device **513**. The memory controller **515** may be implemented as the memory controller **200** of FIG. 1, for example. The processor **511** may display data stored in the memory device **513** on a display unit **530** according to an input signal generated by an input device **520**. The input device **520** may be embodied as a pointing device, for example, such as a touch pad or a computer mouse, a keypad, or a keyboard. The various components may communicate via a bus.

FIG. 15 is a block diagram of a system **600** including an example of the memory system **100** of FIG. 1, according to another embodiment of the inventive concept. Referring to FIGS. 1 and 15, the system **600** may be embodied as a memory card or a smart card, for example.

The system **600** includes a memory system **610** having a memory controller **611** and a memory device **613**. The system **600** further includes a card interface **620**. The memory device **613** may be implemented as the memory device **150** of FIG. 1, for example. The memory controller **611** may control exchange of data between the memory device **613** and the card interface **620**. The memory controller **611** may be implemented as the memory controller **200** of FIG. 1, for example. In an embodiment, the memory device **613** may be packaged in a semiconductor package. The semiconductor package may be mounted on a system board (not shown).

In an embodiment, the card interface **620** may be a secure digital (SD) card interface or a multi-media card (MMC) interface, although the inventive concept is not limited thereto. The card interface **620** may interface exchange of data between a host and the memory controller **611** according to a protocol from the host.

When the system **600** is connected to the host, such as a computer, a digital camera, a digital audio player, a cellular phone, console video game hardware, or a digital set-top box, for example, the host may exchange data stored in the memory device **613** with the card interface **620** via the memory controller **611**. The various components may communicate via a bus.

FIG. 16 is a block diagram of a system **700** including an example of the memory system **100** of FIG. 1, according to another embodiment of the inventive concept. Referring to FIGS. 1 and 16, the system **700** may be embodied as a digital camera or a portable device with a built-in digital camera, for example.

The system **700** includes a memory system **710** having a processor **711** and a memory device **713**. The processor **711** is configured to control overall operations of the system **700**. Also, the processor **711** may include a memory controller **715** configured to control operations of the memory device **713**. The memory controller **715** may be implemented as the memory controller **200** of FIG. 1, and the memory device **713** may be implemented as the memory device **150** of FIG. 1, for example. In an embodiment, the processor **711** and the memory device **713** may be packaged in a semiconductor package. The semiconductor package may be mounted on a system board (not shown).

An image sensor **720** of the system **700** transforms an optical image into a digital signal. The digital signal is stored

in the memory device **713** and/or is displayed on a display unit **730**, under control of the processor **711**. The digital signal stored in the memory device **713** may be displayed on the display unit **730** under control of the processor **711**. The various components may communicate via a bus.

FIG. 17 is a block diagram of a system **800** including an example of the memory system **100** of FIG. 1, according to another embodiment of the inventive concept. Referring to FIGS. 1 and 17, the system **800** may be embodied as a universal serial bus (USB) memory drive or a memory stick, for example.

The system **800** includes a memory system **810** having a processor controller **811** and a memory device **813**. The processor **811** is configured to control overall operations of the system **800**. Also, the processor **811** may include a memory controller **815** configured to control an operation of the memory device **813**. The memory controller **815** may be implemented as the memory controller **200** of FIG. 1, and the memory device **813** may be implemented as the memory device **150** of FIG. 1, for example.

In an embodiment, the memory device **813** and the processor **811** may be packaged in a semiconductor package. The semiconductor package may be mounted on a system board (not shown).

The system **800** further includes a memory **840** that may be used as an operation memory of the processor **811**. The memory **840** may be embodied as a non-volatile memory, such as read only memory (ROM) or flash memory, for example.

A host connected to the system **800** may exchange data stored in the memory device **813** with the processor **811** via a host interface **830**. In this case, the memory controller **815** may also perform functions of a memory interface.

In an embodiment, the system **800** further includes an ECC block **820**. The ECC block **820** operates under control of the processor **811**, and detects and corrects errors in data read from the memory device **813** by the memory controller **815**. The processor **811** may control exchange of data among the ECC block **820**, the host interface **830**, and the memory **840** via a bus **801**.

FIG. 18 is a block diagram of a system **900** including examples of the memory system **100** of FIG. 1, according to another embodiment of the inventive concept. A channel **901** may be implemented using an optical connector. The optical connector **901** may include optical fiber, an optical waveguide, or a medium by which optical signals are transmitted.

Referring to FIGS. 1 and 18, the system **900** includes a first system **1000** and a second system **1100**. The first system **1000** includes a first memory device **100a** and an electrical-to-optical (E/O) conversion circuit **1010**. The E/O conversion circuit **1010** converts electrical signals output from the first memory device **100a** into optical signals, and outputs the optical signals to the second system **1100** via the optical connector **901**.

The second system **1100** includes an optical-to-electrical (O/E) conversion circuit **1120** and a second memory device **100b**. The O/E conversion circuit **1120** converts optical signals received via the optical connector **901** into an electrical signal, and transmits the electrical signal to the second memory device **100b**.

The first system **1000** may further include an O/E conversion circuit **1020**, and the second system **1100** may further include an E/O conversion circuit **1110**. When the second system **1100** transmits data to the first system **1000**, the E/O conversion circuit **1110** converts electrical signals output from the second memory device **100b** into optical signals, and

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outputs the optical signals to the first system **1000** via the optical connector **901**. The O/E conversion circuit **1020** converts optical signals received via the optical connector **901** into electrical signals, and transmits the electrical signals to the first memory device **100a**. The structures and operations of the respective memory devices **100a** and **100b** may be substantially the same as those of the memory system **100** of FIG. **1**, for example.

Embodiments of the inventive concept may be implemented as computer-readable codes on a computer-readable recording medium. The computer-readable recording medium is any data storage medium that can store data as a program, executable by a computer processor and read by a computer system. Examples of the computer-readable recording medium include read-only memory (ROM), random-access memory (RAM), CD-ROMs, magnetic tapes, floppy disks, and optical data storage devices. The computer-readable recording medium may be non-transitory to the extent it does not consist of transitory propagating signals.

The computer-readable recording medium may also be distributed over network coupled computer systems so that the computer-readable code is stored and executed in a distributed fashion. Also, functional programs, codes, and/or code segments for accomplishing the various embodiments can be determined by programmers.

As described above, according to various embodiments of the inventive concept, a memory controller avoids forbidden patterns that may cause data loss, thereby enhancing data reliability.

While the inventive concept has been described with reference to exemplary embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the inventive concept. Therefore, it should be understood that the above embodiments are not limiting, but illustrative.

What is claimed is:

1. A method of operating a memory controller, the method comprising:

determining a data state based on an input stream comprising a plurality of alphabet letters;

converting a part of the input stream, which corresponds to a conversion size, into alphabet letters in a lower numeral system only when the data state is determined to be a first state among a plurality of predetermined data states;

determining whether one of the converted alphabet letters can be output in the data state determined based on the input stream;

mapping the one converted alphabet letter to a different alphabet letter according to a result of the determination; inserting the input stream and either the one converted alphabet letter or the different alphabet letter into a combined stream; and

outputting each of the alphabet letters in the input stream only when the data state is determined to be a second state among the predetermined data states.

2. The method of claim **1**, further comprising:

storing the converted alphabet letters in a first sub buffer, wherein

the part of the input stream is converted into the alphabet letters in the lower numeral system when the first sub buffer is empty.

3. The method of claim **2**, further comprising sequentially inserting converted alphabet letters remaining in the first sub buffer into the combined stream when reception of the input stream is completed.

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4. The method of claim **1**, further comprising:
determining another data state based on read data comprising another plurality of alphabet letters;
restoring a part of the read data to a higher numeral system;
and
inserting the restored part and the read data into combined read data.

5. The method of claim **4**, further comprising mapping each of the alphabet letters in the read data to a different alphabet letter according to the other data state determined based on the read data.

6. The method of claim **5**, wherein a size of the restored part of the read data is the conversion size.

7. The method of claim **1**, wherein:

the first state is one in which at least one of the plurality of alphabet letters cannot be output because the output would create a forbidden output pattern in conjunction with an output of other alphabet letters,

the second state is one in which all of the plurality of alphabet letters can be output, and
the conversion size is determined depending on a size of the input stream.

8. A memory controller comprising:

a pattern transformer configured to:

convert a part of a first input stream comprising a plurality of alphabet letters from a higher numeral system to a lower numeral system only when a data state is determined to be a first state among a plurality of predetermined data states based on the first input stream,

determine whether one of the converted alphabet letters can be output,

map the one converted alphabet letter to a different alphabet letter when the one converted alphabet letter cannot be output, and

insert into a combined stream the first input stream and either the converted part of the first input stream or the converted part of the first input stream with the one converted alphabet letter replaced by the different alphabet letter; and

a pattern de-transformer configured to convert a part of read data comprising another plurality of alphabet letters to the higher numeral system only when another data state is determined to be the first state based on the read data, and to insert the converted part of the read data and the read data into combined read data, the read data being obtained by reading a second input stream that has been written to a memory device, wherein

the first state is one in which at least one of the plurality of alphabet letters cannot be output because the output would create a forbidden output pattern in conjunction with an output of other alphabet letters.

9. The memory controller of claim **8**, wherein the pattern transformer comprises:

a base converter configured to convert the part of the first input stream into the lower numeral system;

a sub buffer configured to store the converted part;

a mapper configured to map the one alphabet letter in the converted part to the different alphabet letter when the alphabet letter in the converted part cannot be output in the first state because the output would create a forbidden output pattern in conjunction with an output of other alphabet letters;

a main buffer configured to store the first input stream and the mapped alphabet letter; and

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a finite state machine configured to determine the data state based on the first input stream and the mapped alphabet letter, and to control the main buffer and the mapper.

10. The memory controller of claim 9, wherein the part of the input stream has a conversion size.

11. The memory controller of claim 8, wherein the pattern de-transformer comprises:

a mapper configured to map each of the alphabet letters in the read data to a different alphabet letter according to the other data state determined based on the read data;

a sub buffer configured to store the mapped alphabet letters;

a base converter configured to restore alphabet letters to the higher numeral system from the mapped alphabet letters;

a main buffer configured to store the read data and the restored alphabet letters; and

a finite state machine configured to determine the other data state based on the read data, and to control the main buffer and the mapper.

12. The memory controller of claim 11, wherein the number of restored alphabet letters is the same as a conversion size.

13. The memory controller of claim 12, wherein the conversion size is determined depending on a size of the second input stream.

14. A memory system comprising:

the memory controller of claim 8; and

a memory device configured to write the first input stream from the memory controller and to read the second input stream under control of the memory controller, and to output a read input stream as the read data.

15. A memory system comprising:

a memory device comprising a memory cell array including a plurality of multi-level memory cells for storing at least one of binary, ternary, or quaternary data; and

a memory controller for converting an input stream received from a host to provide write data that is stored in the memory device, and for converting read data received from the memory device to provide an output stream to the host, the read data corresponding to the stored write data, wherein:

the memory controller is configured to:

convert a part of the input stream comprising a plurality of alphabet letters from a higher numeral system to a lower numeral system only when a data state is determined to be a first state among a plurality of predetermined data states,

determine whether one of the converted alphabet letters can be output,

map the one converted alphabet letter to a different alphabet letter when the one converted alphabet letter cannot be output, and

combine, to provide the write data, the input stream and either the converted part of the input stream or the

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converted part of the input stream with the one converted alphabet letter replaced by the different alphabet letter, and

the memory controller is further configured to convert a part of the read data comprising a plurality of alphabet letters from the lower numeral system to the higher numeral system only when another data state is determined to be the first state based on the read data, and to combine the converted part and the read data to provide the output stream.

16. The memory system of claim 15, wherein the first state is one in which at least one of the plurality of alphabet letters cannot be output because the output would create a forbidden output pattern in conjunction with an output of other alphabet letters.

17. The memory system of claim 16, wherein the memory controller comprises:

a pattern transformer configured to convert the part of the input stream comprising the plurality of alphabet letters from the higher numeral system to the lower numeral system when the data state is determined to be the first state, and to insert the converted part into the combined stream; and

a pattern de-transformer configured to convert the part of the read data comprising the plurality of alphabet letters from the lower numeral system to the higher numeral system when the other data state is determined to be the first state, and to insert the converted part into the combined read data.

18. The memory system of claim 17, wherein the pattern transformer comprises:

a base converter configured to convert the part of the input stream into the lower numeral system;

a sub buffer configured to store the converted part;

a mapper configured to map the one alphabet letter in the converted part to the different alphabet letter when the one alphabet letter in the converted part cannot be output in the first state because the output would create a forbidden output pattern in conjunction with an output of other alphabet letters;

a main buffer configured to store the input stream and the mapped alphabet letter; and

a finite state machine configured to determine the data state based on the input stream and the mapped alphabet letter, and to control the main buffer and the mapper.

19. The memory system of claim 16, wherein the memory controller further comprises:

an error correction code (ECC) encoder configured to encode an output of the pattern transformer to provide the write data; and

an ECC decoder configured to decode the read data to correct errors in the output stream.

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